A Concept of Operations

for a New Deep-Diving Submarine

MR-1395-NAVY

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PREFACE

The NR-1 is the Navy's only nuclear deep-diving research submarine capable of scientific and military missions. Its nuclear reactor will be exhausted in 2012; therefore, NR-1 must be refueled or retired before then. As part of its considerations, the Navy is developing a concept of operations (CONOP) for a possible replacement platform, initially designated NR-2.

The underlying policy issue at hand for this report is the range of capabilities that might be included in such a platform. *This report does not discuss potential alternatives to an NR-2, nor does it analyze the costs associated with the platform.* Rather, the report is designed to provide insight into the capabilities an NR-2 platform might incorporate and help define operational capability requirements based on a prioritization of those capabilities. The results of this study will inform a future follow-on "analysis of alternatives" process, including a cost-benefit assessment. In short, the foci of this report are the definition of the NR-2 missions and the capabilities needed to pursue those missions, not whether an NR-2 should be built. This report and its classified adjuncts do find that any replacement for the NR-1 should surpass the current limitations of the NR-1, especially with regard to redundancy, speed, and payload capacity.

The study integrates and prioritizes NR-1 projected missions and capabilities over the period 2015 to 2050. The result is a potential CONOP—including both scientific and military missions—for a potential NR-2 platform. RAND, working closely with the Navy, developed this CONOP. Qualified civilian scientists, defense experts,

and naval officers contributed to the CONOP. This report should be of interest to defense policymakers and other government decision-makers.

This research was conducted for Naval Sea Systems Command (NAVSEA) within the Acquisition and Technology Policy Center of RAND's National Defense Research Institute (NDRI), a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Commands, and the defense agencies.

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SUMMARY

BACKGROUND

The nation has one deep-diving nuclear research submarine—the NR-1. The NR-1 was built in 1969. Its design for prolonged (30-day) operation on or near the sea bottom at a speed of up to 4 knots separated it from the majority of other deep submersibles. These had been essentially adjuvant vehicles operated from surface vessels, thereby either subject to conditions in the water column or on the surface, and having limited mobility.

The NR-1 has been employed for the past 32 years in a wide range of missions. NR-1 missions included support to national agencies, which had found other assets limited in their ability to complete such tasks as mapping the *Challenger* debris field despite inclement weather or locating important forensics information from the Egypt Air Flight 990 disaster. The NR-1 has also been used in support of maritime archaeology, scientific research, and military operations.

The NR-1 is a small nuclear submarine, but the ancillary equipment on board used in the aforementioned missions also readily supports national security missions. The ship's endurance is limited only by its food and air supply. Unlike most nuclear submarines, it has viewports and the crew can handle small objects with manipulators. NR-1 has two retractable rubber-tired wheels that support it on the ocean bottom. It has thrusters to maintain depth without forward movement, to move laterally, and to rotate within its own length.

The Navy anticipates that the NR-1 will require refueling or replacement by 2012.

THIS REPORT

This report summarizes the results of RAND's support of the Navy's study to gain insight into the range of operational requirements for an NR-1 replacement.

RAND's role in this effort was to assist the Navy in identifying the range of both scientific and military missions a follow-on to the NR-1 would likely be required to execute in the future and to assist the Navy in establishing the range of capabilities that would have to be incorporated in the NR-2[1] to accomplish those missions and to prioritize both missions and capabilities.

The other issues that presented themselves in the course of the study and were addressed by RAND included the need for a follow-on to the NR-1, investment considerations, the need for manning, and initial design concepts.

The study integrates and prioritizes projected deep-submergence missions and capabilities over the period 2015 to 2050. The result is a potential concept of operations (CONOP)—including both scientific and military missions—for an NR-2. The CONOP developed for this report describes and prioritizes these missions. Required NR-2 operational capabilities are associated with missions. Therefore, these capabilities can be prioritized in the course of design trade-off studies.

The basic framework for the study was provided by the results of three conferences, where experts in both science and national security contributed to defining a total of 28 likely future mission profiles, which were then used to derive the prioritized design-driving capabilities for a replacement ship for the NR-1.

RAND assisted the Navy by proposing this framework for prioritization of important capabilities. RAND also summarized the effort and developed for the Navy the general military, scientific, and support CONOP for a possible follow-on system to the NR-1. RAND also developed overall conclusions regarding the need for a system that could incorporate the aforementioned capabilities.

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[1]NR-2 is used here to designate a potential replacement system for NR-1.

SUPPORT OF SCIENCE MISSIONS

The NR-1 has demonstrated its value in support of science by increasing the range, endurance, and power available on the seabed compared to other available means. Also, NR-1 was valued in operations on the ocean floor and in the water column for its speed, flexibility, and ease of operation under adverse conditions. Scientists who participated in the study anticipated applications for NR-2 in all branches of ocean science. They also foresaw the ability to do science more quickly, thoroughly, and accurately. The NR-2 will support all areas of ocean science and national oceanographic research on the ocean bottom.

This study determined the likely science research priorities over the lifetime of the NR-2, as shown in Figure S.1.

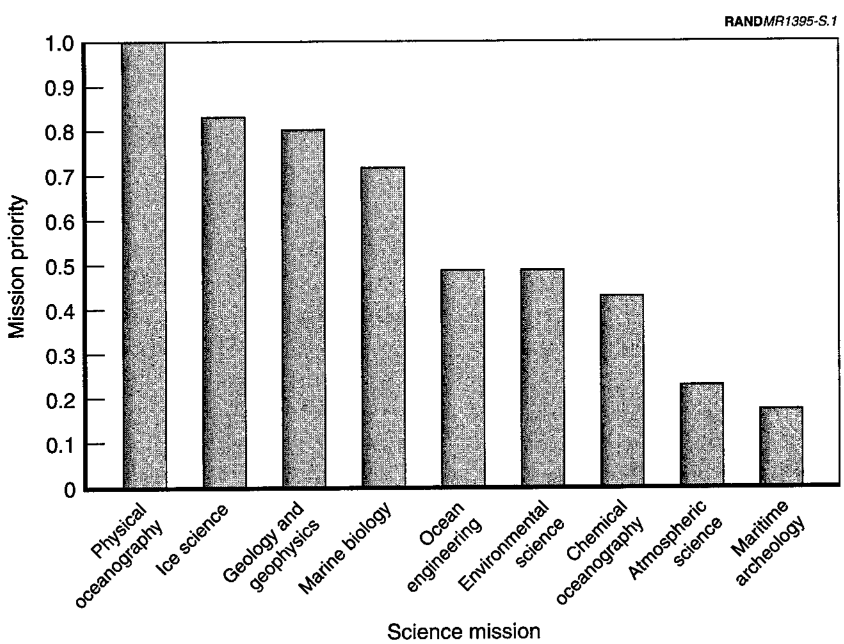

Figure S.1—Science Research Mission Priorities

SUPPORT OF NATIONAL SECURITY MISSIONS

The future use of the NR-2 in support of national security derives from two predominant considerations. First, the ocean bottom has become the infrastructure foundation on which the international telecommunications industry has come to rely, with the concurrent increasing importance of the ability to protect and ensure this infrastructure.

Second, just as the United States has maintained the capability to understand the extent of its adversaries' use and exploitation of space, the country should not cede its ability to provide an understanding of these same aspects with respect to the ocean. National security mission priorities result from the fact that the NR-2, if built, would be the only dedicated national asset capable of this national security mission set associated with the sea bottom. Figure S.2 shows the prioritized national security missions for an NR-2 as determined by this study.

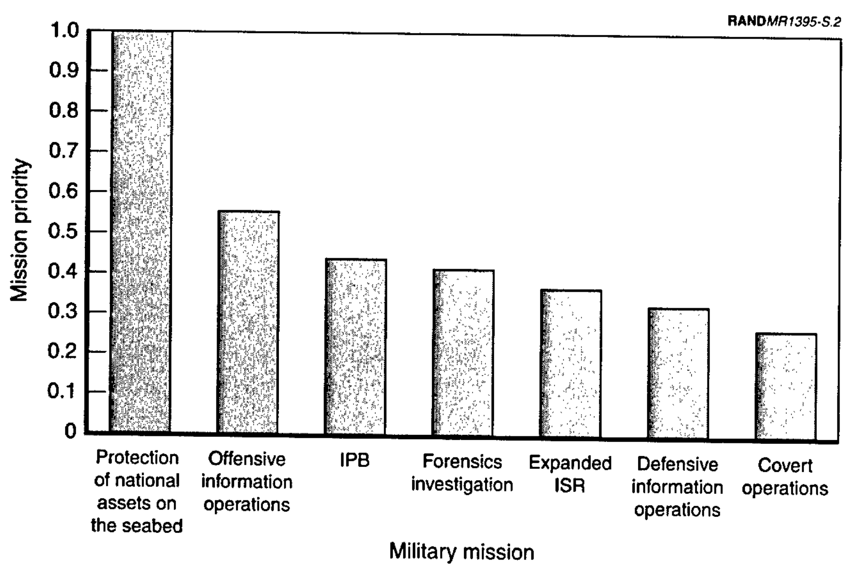

Figure S.2—Military Mission Priorities

STUDY FINDINGS

Mission

After examining a full range of likely future missions in support of both military and science, the study concluded that, if built, the NR-2 would be of national importance; it would be the only naval asset with a dedicated capability of *operating on or near the ocean bottom*[2] to:

- Support national oceanographic research on the ocean bottom.
- Enable national understanding of our adversaries' exploitation of the ocean bottom.
- Enable the protection of U.S. national assets on the ocean bottom.

Lack of NR-2 capability will forfeit this mission.

Capabilities

To execute the aforementioned mission, the following *system* capabilities are required:

- The ability to operate, directly or through an adjuvant vehicle (remotely operated vehicle/autonomous undersea vehicle—ROV/AUV), on or near the seabed at depths to 1,000 meters or more, with sufficient mobility over the bottom to cover tracks hundreds of miles long and to maneuver precisely over the seabed.
- The ability to operate an adjuvant vehicle (to maximize mission flexibility and ability to incorporate new technologies).

[2]Although other sources of capability may be available, it is our sense that they may not be as efficient or cost-effective as the system discussed in this report. Alternatives to NR-2 other than a manned submersible may be precluded by simultaneous requirements for depth, endurance, stealth, speed, reliability, and heavy-lift and manipulation capabilities and by the need for the ability to operate on or near the bottom with intelligent responses to novel situations. However, this matter is beyond the scope of this report and should be resolved in an analysis of alternatives (AoA) study.

- Operator-in-the loop (required for intelligent response to novel situations and reliability over the periods of interest).
- Stealth to penetrate and operate undetected over a period of days in hostile waters.
- Sufficient mobility between theaters to be responsive to both theater and national command authorities (NCA)[3] taskings and to explore areas of interest in a timely manner.
- Design flexibility/adaptability—the ability to accommodate additional missions without redesign or modification to the basic platform.
- Fine object manipulation ability, directly or through an adjuvant vehicle.
- Precise navigation ability to locate or relocate objects on the seabed.

RAND Conclusions

RAND concluded that these capabilities should be developed because

- the missions requiring undersea capabilities in national security and homeland defense will grow in scope and importance, and will exceed the capabilities of the NR-1;
- national oceanographic research support will remain important; and
- the aforementioned capabilities will support the National Oceans Policy and would be consistent with the "Oceans Act of 2000" (see Appendix H).

RAND also concluded that the range of these essential capabilities described above will not be available from any single source other than a follow-on submarine to the NR-1.[4]

[3]"National command authorities" (NCA) refers to the President, the Secretary of Defense, or their deputized alternates or successors" (DoD, 1994).

[4]See footnote 2.

Investment Considerations

The private sector was considered as a possible provider to support this national need. In the case of the NR-2, it is the preliminary judgment of the RAND researchers that [5]

- the private sector will not be able to provide the range, breadth, and depth of expertise and information that the NR-2 will likely be tasked to provide because it will be unprofitable;
- information that the NR-2 will provide will not or could not be reliably collected by the private sector or alternative platforms because it would be too operationally or technologically demanding;
- the information the NR-2 could be called on to collect cannot or will not be collected by other platforms because of risk or other constraints; and
- NR-2 will at times be required to provide U.S. agencies with specific tailored products independently or combined with other sources.

DESIGN CONCEPTS

Two alternative submarine design *concepts* for NR-2 emerged from this study. Both concepts would share design flexibility, ample payload capacity, and the ability to operate at depths to 3,000 feet and to bottom. Both would be able to operate an adjuvant vehicle with a manipulator and would themselves have fine manipulators. Both would have a burst speed capability of 15 to 20 knots. Neither would carry weapons or would have shock hardening. Under-ice capability would increase versatility to scientists by allowing operation over a wider geographic area.

One design concept is for a submarine capable of autonomous operations under all conditions. This submarine would have transit speed (15 to 20 knots) to enable timely response to NCA tasking;

[5]RAND recommends the issue of obtaining these required capabilities commercially be further examined in the course of the AoA study.

endurance (about 60 days) to give it useful time on station; and, for missions in hostile waters, enough stealth (state-of-the-art acoustic and magnetic quieting) to avoid encounters during its mission.

An alternative design concept is for a submarine capable of autonomous operations under all but the most stressing conditions. It would have a transit speed of 10 to 15 knots, about 45 days of endurance, and acoustic and magnetic quieting comparable to the SSN-688 nuclear attack submarine. It would be acoustically quiet at low speeds (6 to 10 knots) but might be relatively noisy at higher speeds. It would be designed for SSN tow or "piggyback." The SSN escort would compensate for the greater detectability of NR-2 in two ways. First, the NR-2 would spend much of the mission inoperative, passively mated to the SSN, making the NR-2's higher-speed signature moot. Second, when the NR-2 was operating, the presence of the SSN would protect the NR-2 and deter potential attackers.

This submarine could perform most military missions autonomously. It could, for example, autonomously inspect bottom objects on the U.S. continental shelves. In response to urgent NCA tasking it could be towed into an area of interest, and the SSN escort could recover it after it performed its mission. The SSN would remain in the region as the NR-2 conducted its mission.

Both design concepts robustly support the majority of ocean science mission needs. The RAND team acknowledges the support for under-ice capability that was expressed by civilian experts and reflected in the body of the report. Absence of under-ice capability is based on the following key points:

- The inclusion of under-ice capability requires compromise; other capabilities would be displaced in this small submarine to accommodate the additional ship control and safety features required for under-ice operations (as a result of the proposed concepts of operations the *redundancy* needed for operation under the ice will be included in both design concepts).[6]

[6]The assessment of relative impacts of specific capabilities on design is outside the scope of this report. The RAND team recommends that the Navy explore the tradeoffs associated with under-ice capability for an NR-1 replacement.

- Arctic capability affects branches of science to varying extents; also, current and likely future methods are available to obtain needed information in the Arctic, for example, ice thickness.
- While many important science missions for the NR-2 could be under-ice, there remains ample science to be supported in the open ocean. Both design recommendations stress the need for the NR-2 to strongly support the widest synergetic selection of science and military missions.[7]
- Experts see no current need for under-ice capability for military missions.

Manning

To be successful, NR-2 must be a manned vehicle for at least two reasons. The NR-2 mission has implicit in it the requirement for responsive evaluation of potentially unprecedented information and extemporaneous mission events—that is, analysis and evaluation of information. In addition, one of the principal capabilities that will assure NR-2 effectiveness over her lifetime is her ability to employ highly capable ROVs, which can be modernized as required to keep pace with technology over her lifetime. Manning the vessel is the key to the capacity for in-situ analysis/evaluation/reaction, ROV employment, and mission reliability.

[7]See *Assessing the Benefits and Costs of a Science Submarine* (Meade et al., 2001) for an amplifying discussion of the benefits of submarines to science in the Arctic.

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However, the information, judgments, analyses, and recommendations contained in this study are entirely the responsibility of the authors.

ACRONYMS

AoA	Analysis of alternatives
AOI	Area of interest
AOR	Area of responsibility
ASDS	Advanced Swimmer Delivery System
AUV	Autonomous undersea vehicle
CINC	Commander in chief
COMEX	Commence Exercise
CONOP	Concept of operation
CONUS	Continental United States
CORE	Consortium for Oceanographic Research and Education
DOTS	Deep-Ocean Transponder System
DR	Dead reckoning
ESC	Electronic still camera
GB/s	Gigabytes per second
GPS	Global Positioning System
HDR	High data rate
HF	High frequency
HITS	Hull Integrity Test Sites
HUMEVAC	Humanitarian Emergency Evacuation
IMINT	Imagery intelligence

IPB	Intelligence Preparation of the Battlespace
ISR	Intelligence Surveillance and Reconnaissance
LDGO	Lamont-Doherty Geological Observatory
LLL	Low light level
LLS	Laser Line Scanner
MB/s	Megabytes per second
MIZ	Marginal Ice Zone
MOT	Mark on Top
NAN	Navy After Next
NAVOCEANO	Naval Oceanographic Office
NAVSEA	Naval Sea Systems Command
NCA	National command authorities
NDRI	National Defense Research Institute
NOAA	National Oceanographic and Atmospheric Agency
NSF	National Science Foundation
NURP	Naval Undersea Research Program
NUSC	Naval Undersea Systems Command
OAS	Obstacle Avoidance Sonar
OIC	Officer-in-charge
ONR	Office of Naval Research
OpArea	Operating Area
PPM	Parts per million
R&D	Research and development
RF	Radio frequency
ROV	Remotely operated vehicle
SBS	Sub-Bottom Scanner
SCICEX	Scientific Ice Experiments
SLS	Side-Looking Sonar
SOF	Special Operations Forces

SPAWAR	(Naval) Space and Warfare Systems Command
SS	Single Screw
SSBN	Ballistic Missile Submarine
SSN	Nuclear Attack Submarine
SVP	Sound Velocity Profile
SW	Seawater
TD	Towed device
TS	Twin screw
USGS	U.S. Geological Survey
USNS	U.S. Navy Ship
UUV	Unmanned Undersea Vehicle
UWT	Underwater telephone
VB	Variable ballast
WHOI	Woods Hole Oceanographic Institute

Chapter One

INTRODUCTION

REPORT

This report summarizes the results of RAND's support of the Navy's efforts to determine the range of capabilities that would be required of an NR-2. If built, the NR-2 would replace the NR-1, the Navy's only nuclear-powered deep-submergence ocean research submarine. Built in 1969, the NR-1 has operated for 32 years and has been refueled and modernized twice. Based on current projections, the Navy anticipates that the ship will require refueling or replacement by 2012, 43 years after it was placed in service.

PURPOSE

To begin the acquisition process for a replacement submarine, this concept of operations is intended to formulate input to the ship design process. This will then allow an analysis of alternatives (AoA) to weigh the various approaches to accomplishing the missions and providing the capabilities identified herein and the associated cost-benefit trade-offs.

BACKGROUND

Over the past 32 years, the NR-1 has continually proven of great benefit to the Navy and, more important, to the nation. For example, because of weather conditions in the vicinity of the *Challenger* disaster debris field, the NR-1 was the single national asset capable of early operation in the area and debris field mapping. NR-1 was also

used as a national asset following the October 2000 crash of Egypt Air Flight 990. The scientific community has used NR-1 extensively in the area of deep-ocean research and other fields. On the other hand, although the NR-1 is a unique Navy asset, it has not been tasked extensively as a military asset, and the future will hold both additional opportunities and challenges for a vessel like NR-1 if it is assigned more routinely to military operations.

STUDY PURPOSE

Identifying and prioritizing those scientific, military, and support missions that would likely be assigned to the NR-2 over its planned operational life can clarify concepts of operation for the NR-2. Along with those concepts, mission priorities can then be clarified to prioritize the operational capabilities of NR-2.

SOURCES

Our assessment was based primarily on the inputs of the expert participants in three conferences. These were to a large extent operational, scientific, academic, and national security experts. In operational assessments, we weighted most heavily the inputs provided by the former officers-in-charge (OICs) of NR-1. To mitigate potential biases, expert participants included military and scientific personnel familiar with alternative methods of accomplishing missions. In addition, following the conferences, RAND consulted additional outside sources familiar with alternative methods.

METHODOLOGY AND LIMITATIONS

For each of the three conferences, we used a "Group Systems" decisionmaking support approach. Using this approach, conference participants used networked laptop computers to discuss, analyze, and prioritize potential mission tasks and capabilities for a new deep-diving submersible. Participants were encouraged to discuss these options but also to submit comments and prioritize items anonymously, via computer network. While the process did not allow a completely thorough discussion of trade-offs and alternatives or analytical points, it did yield a useful set of data, insulated from

the potential distortion of rank or seniority, regarding potential missions, tasks, and capabilities. The process may not be flexible enough to incorporate new scientific ideas. Further, the approach does not eliminate biases, but does allow the analyst to highlight and isolate them. Although this report summarizes RAND's support of a Navy study, RAND has in Appendix I highlighted one potentially important example of the utility of an NR-2: assistance in protecting the nation's undersea communications infrastructure.

Based on RAND research, a follow-on to NR-1 could be of greater benefit to science than was described in this study. For example, because of its combination of range, power, endurance, and ability to work on or near the bottom, it could begin ocean sub-bottom exploration for the first time. RAND recommended to the Navy that it explore the broader benefits of an NR-2 to our understanding of the world's oceans.

ORGANIZATION

- Chapter Two contains background on the NR-1, its historical missions and capabilities.
- Chapter Three contains the description and prioritization of scientific missions.
- Chapter Four contains an initial assessment of military mission and priorities, attendant NR-2 concepts of operations (CONOPs), and military capabilities.
- Chapter Five contains the final assessment of military missions.
- Chapter Six contains conclusions.

Several appendices follow the report, discussing in greater and more technical detail topics covered in the body of the report.

Chapter Two

NR-1

NR-1 DESCRIPTION AND CAPABILITIES

Because the primary focus of this effort is to determine the range of capabilities that a replacement platform for the NR-1 would require, this chapter discusses the capability set that will be lost if the NR-1 is retired in 2012. As capability requirements in Chapters Three and Four are generated and prioritized for the replacement system, this chapter is intended to show the baseline or "state of the art" of the current system at sea. To discuss the potential capabilities of an NR-2, it is important to examine the previous missions by the NR-1. This chapter briefly describes the NR-1 deep-submergence submarine and overviews its capabilities.

NR-1 was designed with an emphasis on prolonged operation on or near seabeds at depths to 3,000 feet. Whereas other nuclear submarines are not designed for prolonged operation on or near the sea bottom, NR-1 has two retractable rubber-tired wheels that support it on the bottom (Figure 2.1). NR-1 is also equipped with two pairs of thrusters, which enable it to maintain its depth without forward movement, to move laterally, and to rotate in its own length.

NR-1 was not designed to operate autonomously. It has a top speed of 4 knots (about 4 miles per hour), so is normally towed to and from operating areas by a dedicated support ship. Also, it cannot replenish its own compressed air system (needed to blow seawater out of ballast tanks to surface, to recharge scuba equipment, and for emergency breathing). Its surface support ship can replenish the compressed air system.

NR-1 has three viewports providing a view forward and down, complemented by 25 external lights, low light level (LLL) cameras, LLL zoom cameras, a color video camera, an electronic still camera (ESC), and other vision aids. It is equipped with sensors for basic environmental data and the means to record scientific data. Seawater can be sampled through the ship's depth-gauge system.

Complementing its viewing systems, NR-1 is equipped with a variety of sonars. It has Obstacle Avoidance Sonar that, along with its safety purpose, can be used to search and map the bottom. Side-Looking Sonar (SLS) can be used to map the seabed to both sides, and a Laser Line Scanner enables high-precision bottom mapping.

NR-1 uses the Global Positioning System (GPS) and other navigation systems on the surface. When near the bottom its Doppler sonar provides precise position (accurate to about a foot) relative to the bottom. Together with its SLS or Laser Line Scan system, the Doppler sonar makes it possible to accurately map such regions as aircraft debris fields.

When submerged but not near the bottom it uses dead reckoning[1] to estimate its position. Also, the NR-1 support ship can track it acoustically and communicate NR-1's position to it.

NR-1 can manipulate objects with manipulator operators stationed inside the viewing ports. Its manipulator can handle small objects (no more than eight inches in diameter) and place them in sample baskets for storage. It also has a recovery claw for somewhat larger objects. The manipulator lacks operator feedback and can inadvertently crush fragile objects. A special NR-1 tool is its "jetter"—a water jet system for uncovering or burying objects on the bottom.

Physically, NR-1 is a small nuclear submarine. It is about 145 feet long; it is 96 feet long inside the pressure hull. Its beam (maximum diameter) is 12.5 feet. The nuclear propulsion plant provides endurance limited only by its food and air supply. NR-1 can sustain

[1]Dead reckoning is the process of estimating position by advancing a known position, using course, speed, and time.

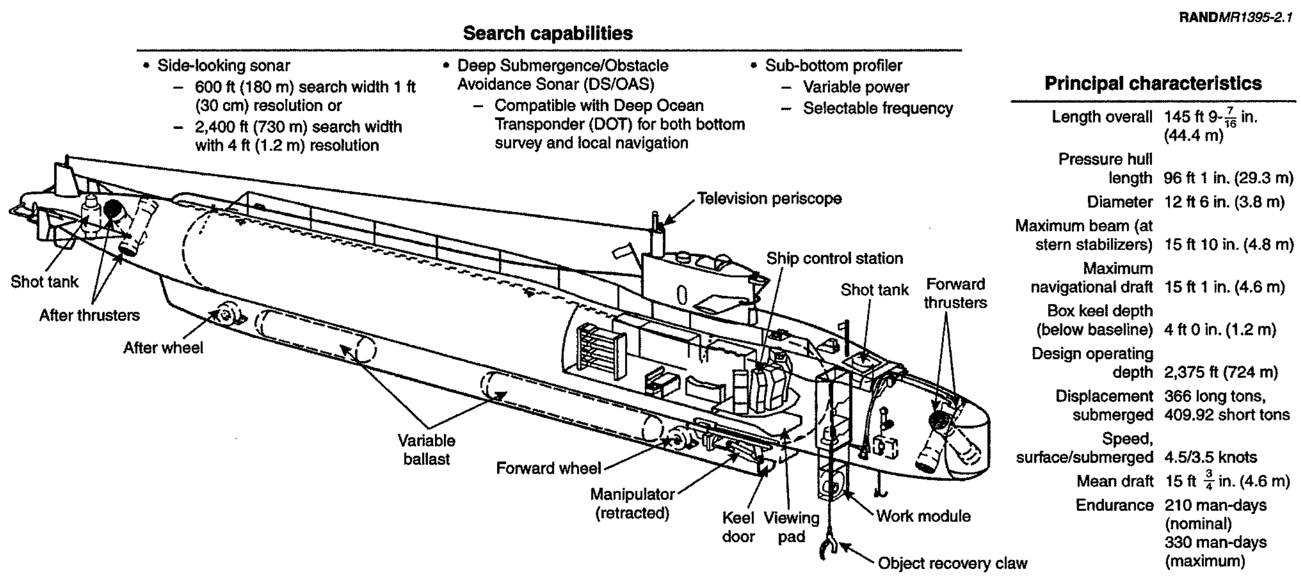

Figure 2.1—Summary of NR-1 Features

its regular crew plus two scientists for up to 30 days. Unlike modern U.S. nuclear submarines, NR-1 uses a chlorate "candle" system to generate oxygen. A catalytic converter removes carbon monoxide and hydrogen from the atmosphere. Replaceable lithium-hydroxide canisters remove carbon dioxide.

In case of an emergency, NR-1 carries 11 tons of expendable lead shot to increase buoyancy and return to the surface in conjunction with an emergency blow. It can communicate by radio when on the surface. Its high-frequency (HF) radio permits long-range communications. The ability to sit on the bottom also provides a refuge for NR-1 in an emergency.

NR-1 CAPABILITIES REVIEW

This chapter briefly describes the NR-1 deep-submergence submarine and overviews its capabilities.

The following capability insights are based on reviews of 34 of the NR-1 scientific and military operations and missions conducted from 1972 to 1995.

Bottoming

The ability to bottom the ship was used often in scientific and military missions and, based on this study, reasons for a bottoming capability are expected to apply in the future, including the following:

- Bottoming facilitates manipulation tasks, especially where the submarine must hold a position against a cross current or water column motion. For example, critical components of an F-15E fighter aircraft were recovered in water 120–150 feet deep. With five- to seven-foot waves, there was vertical movement throughout the water column. There was no way to compensate for this movement with thrusters or ballast control. Only by bottoming, with thrusters holding the ship down and an additional 1,000 pounds of ballast, was reasonable stability achieved.
- Bottoming facilitates "look but don't touch" operations from close aboard. In a military mission, NR-1 visually examined

exercise mines as though they were actual mines. This was accomplished by bottoming at a safe distance from the exercise mines once they were located. In a science mission to examine manganese nodules, it was possible to examine the nodules in situ under different lighting conditions but from the same angle by bottoming. It also gave scientists time to carefully select nodules for sampling.

- Bottoming provides an alternative to anchoring, especially above rock/coral bottoms. These conditions prevailed during the previously mentioned F-15E component recovery effort.
- Bottoming provides a "safe mode" to be used during engineering casualties to minimize operational impact of those failures. For example, the NR-1 Obstacle Avoidance Sonar (OAS) failed during one mission and the NR-1 could not proceed safely without it. Instead of surfacing, it bottomed briefly to conduct repairs and continued its mission when the repair was completed. Lines streaming from NR-1 were easier to cut loose using the manipulator after bottoming.
- Brief bottoming periods provide the ability to "pause" missions. For example, when a science survey was completed earlier than scheduled, NR-1 was bottomed, a new plan was developed, and the science mission resumed in area.

Ability to bottom adds to NR-1 versatility. Ability to bottom more securely on rock/coral bottoms may be desirable.

Anchoring

NR-1 rarely used its anchor. The original anchoring system, with a single forward anchor, did not provide adequate stability. The present anchoring system, with a single aft anchor, provides no more stability and is problematic when there is a current.

Wheels

NR-1 rolled across the bottom for a few low-priority tasks. Rolling was not used for cable, gas pipe, or oil pipeline inspections.

- Rolling is a way to remove entanglements such as lobster pots or loose lines.
- Rolling can be used to disturb the bottom deliberately. In conducting searches for methane gas seepage sites, NR-1 was bottomed to see if a plume of methane would be released.
- Wheels provided an ability to fine-tune NR-1's position on the bottom, which was used in missions requiring fine manipulation. A hovering submarine cannot be maneuvered as precisely as a bottomed submarine using wheels. Also, currents tend to swing hovering submarines. Precise position adjustments could be accomplished reliably only by bottoming and using the wheel system.

NR-1 tasks accomplished by rolling might have been performed by other means. The manipulator arm or divers can remove entanglements, and a relatively recently installed line-cutting system has reduced the entanglement problem. In searching for methane seep sites, for example, NR-1 might have dragged a weighted line over the bottom to disturb it instead of rolling across it.

The "bicycle" wheel system provided limited stability when NR-1 was bottomed. Also, the OIC during the F-15E component recovery mission was concerned for the wheel suspension system as NR-1 bounced on the bottom with movement in the water column.

Reliable fine-position adjustment on the bottom regardless of currents is a valuable NR-1 capability. While the stability provided by wheels should be improved, the "fine positioning" ability is satisfactory and should be retained.

Viewports

Viewports were used heavily in NR-1 operations. In some instances they might have been replaced by video cameras. In operations close to the bottom they were invaluable for own ship safety.

- Scientists frequently used viewports heavily; no training or adaptation is required to use a viewport.

- High-resolution real-time imagery was required at various times (e.g., to read serial numbers off mine release mechanism components, to identify pieces of wreckage, or to identify shipwrecks).
- Viewports remain the only means of accurately determining NR-1 altitude in operations close to the bottom. Video images are two-dimensional, making it difficult to estimate distances accurately. Sonars do not work at the ranges in question. Only viewports provided the three-dimensional view of the bottom that enables safe operations near the bottom.

Viewport problems and limitations were apparent. In unusually turbid water, with visual ranges down to five or ten feet, viewports had little value. Viewport geometry also was a sometime problem. For example, it is difficult to use a viewport to see under a piece of wreckage (such as an F-15E fuselage). Similarly, it is difficult to see up a vertical object from a viewport located under the bow. On one mission, NR-1 encountered a steep rise without warning (see subsection on "Sensors" below for a discussion of OAS performance). It could not determine the height of the rise with its sonars and the top of the rise could not be seen through viewports. The location of the viewports 30 feet from the bow and under it reduced their effectiveness.

The capability to view the bottom in three dimensions is crucial to ship safety in operations near the bottom. Thought should be given to better visibility from any NR-2 viewport.

Object Manipulation

NR-1 can manipulate both small and large objects. Small-object manipulation was used, for example, in selecting nodules of interest to scientists and in placing, using, and recovering science equipment. Large-object manipulation was used primarily in recovery operations. Ejection seats, canopies, and other large objects were manipulated in the recovery process.

Limitations in NR-1's ability to manipulate objects have been noted. NR-1's manipulator lacks fine control. Its "grip" was occasionally inadequate—the F-15E canopies posed a great challenge. Also, it

lacks feedback. In the *Challenger* recovery operation some debris recovery was prevented by the risk that the manipulator would have crushed fragile debris. This is one of the few instances that NR-1 was on site but could not perform a desired task.

The ability to manipulate large and small objects is expected to be key to NR-2 success and should be retained. Finer manipulation control and operator feedback would increase its utility.

Thrusters

Thrusters were essential to success in several missions. They were essential in the following cases:

- NR-1 had to be held against a cross current and bottoming was not an option (because of bottom conditions).
- Thrusters were needed to maneuver NR-1 safely out of tight spaces, such as sinkholes.
- Thrusters were used to help keep NR-1 bottomed against wave action in shallow water.

While operating near F-14 wreckage on the bottom, the OIC log tersely noted that NR-1 had "experienced sudden, dramatic increase in current (up to 1.5 knots). Sort of lost control of ship." In another mission, NR-1 encountered a bottom suction problem and had difficulty freeing herself from the bottom. Thrust for pulling NR-1 off the bottom was adequate under normal operating conditions. NR-1 occasionally encountered situations in which more powerful thrusters would have been desirable.

Divers

Divers demonstrated their utility in several NR-1 missions.

- NR-1's manipulator was disabled during the F-15E recovery mission. The problem could not be fixed from within NR-1 but was easily fixed by divers.
- Divers were needed to attach lift bags to heavy objects to be recovered; single manipulators are unsuited to this task.

- In the F-15E component recovery mission, NR-1 was able to lift ejection seats and canopies only with its grapnel. These were then raised to beneath the NR-1 bow, but NR-1 could not deal with these objects beyond that. Divers attaching lines to the objects were required to complete recovery.

The ability to work with divers is satisfactory and should be retained.

Sensors

- The most commonly used sensor on NR-1 is its OAS. It was used for ship safety, to search debris fields, to locate hardware equipped with pingers, and to assist in tow hookup. An OAS better than that installed in 1993 is recommended. There have been reports that "the bottom came up rapidly" as the OAS did not recognize steep rises. Also, OAS is a forward-looking sonar. Sometimes, such as when NR-1 had to back up, a 360-degree field of view would have been helpful.

- SLS is also a valuable sensor. It has been used for geologic surveys in science. It is also well suited for imaging shipwrecks and for surveying debris fields.

- Laser Line Scanner (LLS) systems have also been useful. Parallel gas pipe/oil pipeline systems have been scanned simultaneously by examining one with SLS and the other with LLS. Existing LLS systems can also "see" beyond visual ranges. Thought should be given to extending LLS ranges, perhaps using blue-green laser technology.

- Sub-Bottom Scanner (SBS) systems have the unique ability to help the submarine locate geologic fault lines. This system operates like sonogram technology—a noise source is pressed against the region to be scanned, resulting in images of internal structure. SBS is important when there is risk to bottom systems from fault line slippage.

- ESC images had good quality, their images were available in real time, and they never ran out of film or experienced the flash synchronization problems seen with 35-mm still cameras.

Navigational Accuracy

Navigation accuracy is important in scientific and military missions. For example, NR-1 has been directed to examine specific exercise mines or to map mine-like objects and debris fields. While NR-1 knew the exact location of the mines of interest, it did not know its own position with sufficient accuracy to go directly to them. Instead, it had to search the bottom for objects with known locations. This mission succeeded in part because the crew gathered serial numbers in advance of the mission. When an exercise mine was located, the serial number from the mine-release mechanism told them the NR-1 position in the field. In the recovery of F-15E components, USS *Grasp* identified the location of the debris field prior to NR-1's arrival. However, NR-1 still had to search for the debris field because it did not know its own position with sufficient accuracy to go directly there. In the water column it depends solely on inertial navigation, and that system drifted during the descent.

Early on, the problem of limited navigation accuracy was solved most frequently using a Mark on Top (MOT) from an escort ship. The NR-1 bottoms or hovers for the MOT and ship position is read at MOT. The need for MOT has since been eliminated. Instead, escort ships use a track-point sonar that provides NR-1 position relative to the escort ship, which knows its position with GPS accuracy. The most accurate NR-1 navigation tool is a Doppler sonar that can establish relative position with accuracy on the order of one foot. This allows NR-1 to return to an object on the bottom or a location with great accuracy so long as it operates near the bottom—Doppler navigation does not work for a submarine operating in the water column. The Deep-Ocean Transponder System (DOTS) has a similar problem.

Improved navigation accuracy is recommended if autonomous operation is planned for NR-2. Requirements for precise navigation are defined by the tasks of locating an object with a known position or recording the position of an object so it can be subsequently relocated ("precise navigation" also includes the ability to *place* an object on the seabed and subsequently replace it). The ability to navigate accurately in the water column will also be required for such science missions as physical or chemical oceanography.

Communication

NR-1 can communicate via radio and underwater telephone (UWT). Its radio suite includes an HF set for long-range communications, primarily intended for emergency use. Its long wire would probably not survive long in under-ice operations.

The UWT was not designed to operate in some of the conditions in which NR-1 operated, and communications were sometimes poor in undersea canyons. A more sophisticated communications suite may be needed for under-ice operations.

Autonomy

NR-1 was not designed for autonomous operation and so rarely operated autonomously. Consort ships provided a variety of services. These include the following:

- Providing tow services to and from mission areas. Towing reduced the time to reach operating areas and reduced operational run time.
- Logistic support. Consorts provided a range of logistics support, including high-pressure air.
- Crew exchanges. The ability to exchange science teams enabled NR-1 to conduct a string of science missions without returning to port. This increased NR-1 efficiency when brief science missions in the same area could be strung together sequentially. Consort ships also provided diver services. The consort ship conducted at least one HUMEVAC.[2] Crewmembers were also rotated using the consort ship.
- Storing retrieved objects. Retrieved objects, such as ejection seats, canopies, and missiles, could not be stored on NR-1 and could not be returned safely in the grasp of NR-1's manipulator. Additional storage was required for successful mission completion. NR-1 lacks the ability to segregate retrieved objects. Consort ships provide separate storage.

[2]A HUMEVAC is an unscheduled/emergency transfer of a crewmember from the ship for humanitarian reasons.

- Supporting large object retrieval. NR-1 was able, for example, to lift F-15E components off the bottom but could not bring them to the surface. A consort ship working with NR-1 accomplished final retrieval.
- Aiding navigation. Consorts provided accurate navigation services during many missions. They were most valuable in such operations as search and recovery or bottom mapping.
- Contributing to bottom surveys. Consorts used their sonar systems to outline debris fields and locate key objects. In the case of the F-15E recovery mission, USS *Grasp* arrived on scene before NR-1 and conducted a preliminary survey for NR-1 to use.
- Providing a surface picture supporting NR-1 ship safety. Surface pictures included area traffic prior to NR-1 surfacing, sea conditions, and forecasts.

Consort ships benefited NR-1. Consort vessels can be expected to be of benefit to NR-2, and NR-2 should be able to work with consort ships.

NR-1 OPERATIONS AND MISSIONS

The following is a list of all known unclassified NR-1 operations and missions, including their dates, objectives, and locations. For operations and missions marked with an asterisk, records have been retained and made available to the National Defense Research Institute (NDRI) for review for this report.

1972	Geological/oceanographic investigation of eastern continental slope of Grand Banks*
1972	Hydrographic/oceanographic operations, undetermined location*
1972	Hudson Canyon oceanographic operations*
1973	Blake Plateau oceanographic operations*
1973	Puerto Rico oceanographic operations*
1974	Lydonia/Gilbert Canyons oceanographic operations*
1975	Transatlantic Telephone VI operations*
1975	Jetter operations*

1976	Jetter trials*
1976	Hudson Canyon bottom exploration operations*
1976	Operation Spacious Sky*
1976	Phoenix air-to-air missile recovery*
1977	Rekyjanes Ridge bottom survey operations*
1979	Trident missile component recovery
1980	Blake Plateau Oceanographic Operations—geological survey for mineral nodules*
1981	Lamont-Doherty Geological Observatory (LDGO) survey operations*
1981	Locate/inspect transponder and locate/input coaxial cable tasked by Naval Undersea Systems Command (NUSC) Detachment Bermuda*
1984	Rekyjanes Ridge survey—marine biology*
1984	Locate fleet ballistic missile submarine (SSBN) propeller
1985	Continental shelf survey—shelf silt drift*
1985	Search for Trident/Pershing missile components
1986	Gulf of Mexico hydrocarbon seeps survey
1986	Space Shuttle *Challenger* debris recovery*
1987	Virginia Capes Naval Oceanographic Office (NAVOCEANO) geodetic survey
1989	Gulf of Mexico various science operations (Texas A&M)*
1989	Dump site survey (National Oceanographic and Atmospheric Agency [NOAA]/National Undersea Research Program [NURP]—examine effect of dumping on sea life*)
1989	Virginia Capes Survey—Recovery of NAVOCEANO Tow Fish*
1989	Blake Plateau survey (U.S. Geological Survey)—sinkhole survey*
1989	Naval Space and Warfare Systems Command (SPAWAR) cable burial—use of jetter*

1990	Charleston Operating Areas Hull Integrity Test Sites (HITS) surveys—detail bathymetric and shipwreck locations for SSN/SSBN sea trials*
1990	Gulf of Maine operations (University of Maine)—marine life and marine biology surveys*
1990	Narragansett Bay bottom survey operations*
1990	Charleston Bump bottom survey operations*
1992–1993	Narragansett Bay operating areas training minefield survey—search for nonresponding acoustic training mines*
1993	Blake Plateau scientific operations—mineral nodules and coral reef surveys
1993	NAVOCEANO surveys Cherry Point operating areas*
1993	Proposed minefield survey*
1993	OAS testing*
1993	Bush Hill, Brine Pool, and Green Canyon*
1993	Viosca Knoll survey*
1993	Oil pipeline survey—search for failure-prone pipeline segments*
1993	Narragansett Bay operating areas survey #2*
1993	Ex-USS *Salmon* operations*
1994	HITS survey(s)
1994	NAVOCEANO surveys Virginia Capes operating areas
1994	Eastern Atlantic SURTASS array recovery
1994	NOAA/NURP science support—various surveys; mid-Atlantic Ridge*
1994	Support to Commander Submarine Development Squadron TWELVE Tactical Development Exercise 13-94
1995	F-15 recovery operations*
1995	Exploration of HMHS *Britannic*, sister ship to *Titanic*, sunk during World War I in the Greek archipelago
1995	Woods Hole Oceanographic Institute (Dr. Ballard) archeological studies in the Mediterranean Sea
1995	NURP geomorphology*

1995	Lightweight torpedo search*
1995–1996	Jason Project—high school students/live TV broadcasts/ship rides—Florida Keys
1996	AOS and acoustic communications research and development
1996	Various scientific surveys (Texas A&M) Florida Keys
1996	NATO support for Norwegian coastline mapping—highlighted by documenting 26 shipwrecks in 24 hours within Bergen Harbor
1997	Archeological and ocean engineering studies in the Mediterranean Sea—Dr. Ballard
1997	Search for Israel Navy submarine INS *Dakar* (lost at sea in 1968)
1998	Low-Frequency Broadband Variable Sonar R&D testing with Naval Undersea Warfare Center
1998	Gulf of Mexico—Texas A&M seabed surveys for geothermal/hydro vents and deep-sea hydrobiology
1998	Bottom survey support for Coast Guard and FBI in investigation of maritime claims against the U.S.
1998	Shallow water initial operations testing of high-resolution side-scan sonar
1999	Bottom search and survey subsequent to the crash of Egypt Air Flight 990

Chapter Three

SCIENCE

MISSIONS

Potential NR-2 missions considered for this study are scientific or military in nature. Military missions for the NR-2 are addressed in Chapter Four.

SCIENCE MISSIONS

Potential NR-2 science missions were derived over a two-day conference and during subsequent follow-up sessions. At the request of the study sponsor, the conference was chaired by a representative of the Woods Hole Oceanographic Institute. A broad group of national program administrators, ocean science academics, and scientists participated. Inputs on capability requirements for a potential replacement for the NR-1 were also requested from NOAA, Consortium for Oceanographic Research and Education (CORE), Office of Naval Research (ONR), National Science Foundation (NSF), and U.S. Geological Survey (USGS) (referred to as agencies in this chapter). These inputs are included in Appendix A.

Scientists provided inputs prior to, during, and after the conference. Submarine design experts were present throughout the conference. A complete transcript of the conference is available separately from RAND.[1]

[1]For an explanation of the voting process used at the conference, see pp. 2–3, under the subhead, "Methodology and Limitations."

Results Summary

The following ocean science categories were identified as reasonable scientific "mission" areas for rough categorization of the ocean science in which the scientific community would utilize the NR-2. Mission areas were not explicitly defined at this time but were used as flexible categories.

- Physical Oceanography
- Ice Science
- Geology and Geophysics
- Marine Biology
- Atmospheric Science
- Ocean Engineering
- Chemical Oceanography
- Maritime Archeology
- Environmental Science.

Prioritization. To begin prioritizing these mission areas, conference participants developed a common understanding of mission areas (mission area profiles and objectives are presented starting on p. 33). The prioritization task recognized the potential for conflicting priorities. Science missions could have great perceived value to scientists in general but low value to potential users, and missions having a high value to users could have a low value to scientists. Recognizing science mission value as multidimensional, priorities were generated based on perceived scientific value, agency willingness to fund missions, and projected importance to the nation in the 2015–2050 period. Only agency representatives participated in the ranking of science missions based on anticipated agency funding. Ranking by scientific value was performed twice—once by scientists and academics only, then by the group as a whole for a total of four prioritizations (Figure 3.1).

Rough consistency among the categories of "agency funding," "national interest," and "scientific interest" is evident in the prioriti-

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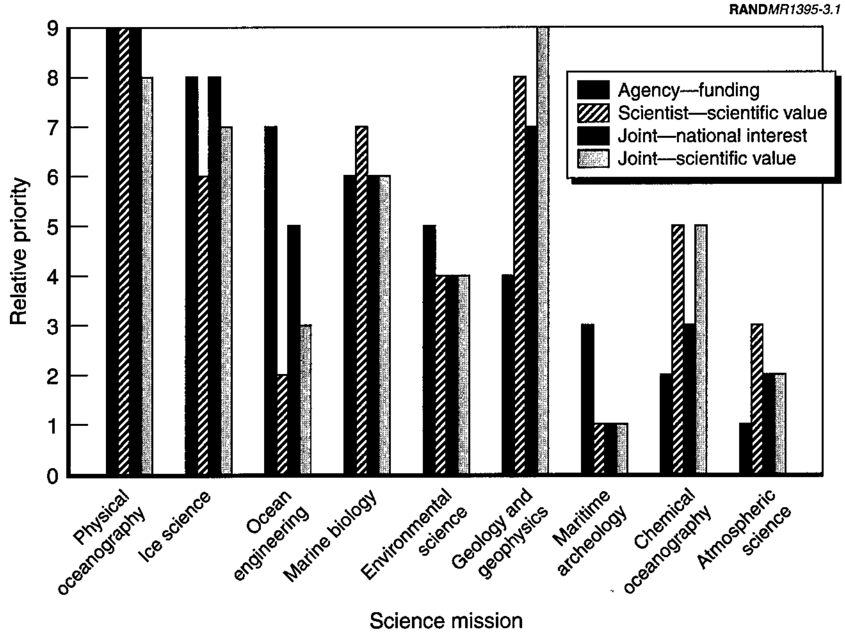

NOTE: Scoring: first place = 9, second place = 8, etc.

Figure 3.1—Priorities of NR-2 Potential Missions in Support of Science

zations.[2] With broad agreement in priorities found, rank total priorities were assigned by adding the rankings for each category across "agency funding," "national interest," and "scientific interest," and prioritizing by the sum for each category. The bars in Figure 3.2 illustrate this process. As a final check, the missions are ranked according to "agency funding" in Figure 3.3, where projected agency funding priority seems broadly consistent with rank total priority.

Further along the path to definition of NR-2 operational capabilities, scientists were asked to give priorities to the principal objectives (or

[2]More rigorously, a statistical examination showed a strong positive correlation in priorities among these categories.

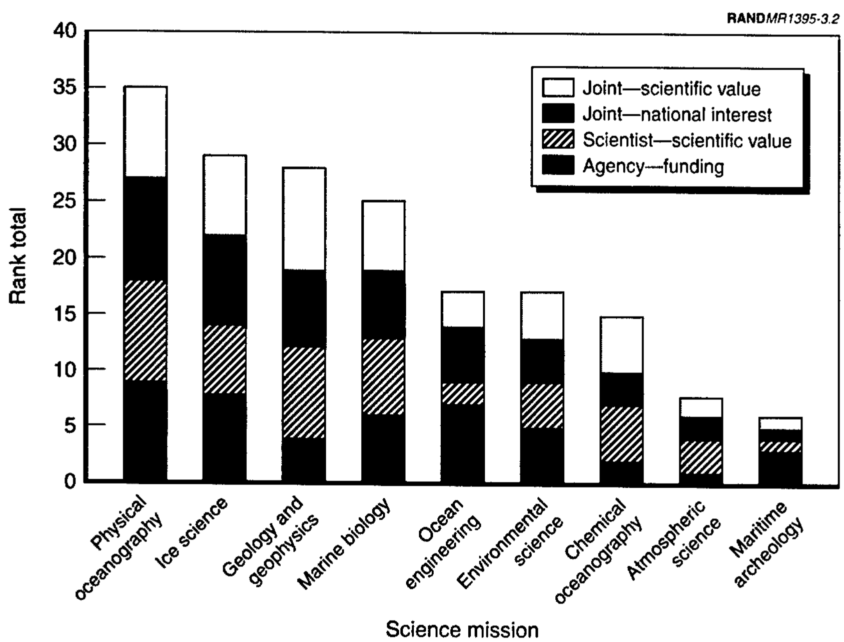

Figure 3.2—Projected Science Mission Prioritization (2015–2050)

subareas) of each scientific mission. Within the discipline of physical oceanography, the participating scientists prioritized the five principal subareas of this branch of oceanography (see Figure 3.4). Conference attendees expressed concern that the results could not be very consistent because of the large standard deviations observed. In fact, much of the apparent dispersion in input simply reflects outlying "opposing views." A single such outlier can significantly skew results measured as averages, or means. To avoid giving these outlying views undue weight, the most commonly voted views (or modes) were used for the rankings. Subareas were then ranked by mode.

The scientists' insights, when plotted in mode order, resemble a mountain range. This illustrates the consistency of thought among

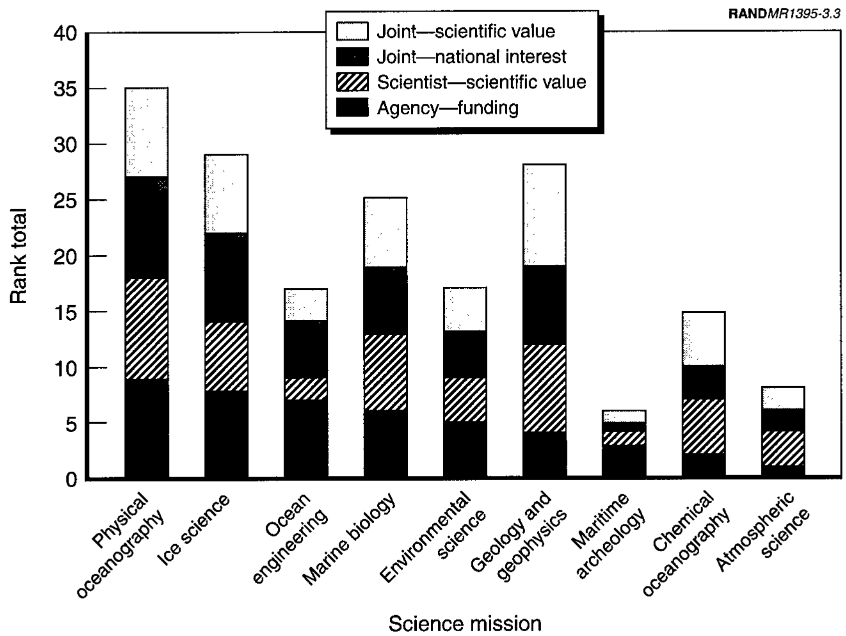

Figure 3.3—Cross-Check—Agency Funding Perspective

the physical oceanography experts with respect to research priorities. In particular, a clear majority of the experts considered mapping upper ocean structure the highest priority within physical oceanography. All experts who did not give it highest priority gave it second highest priority. Looking at the subarea of measuring density flows, convective cells, fronts, eddies, etc., in ice-covered waters, the large majority of the experts ranked this subarea as either most important, second most important, or third most important. This is good response agreement.

The individual science subarea objective prioritization was completed for each scientific field and is presented in the subsequent discussion of science mission profiles.

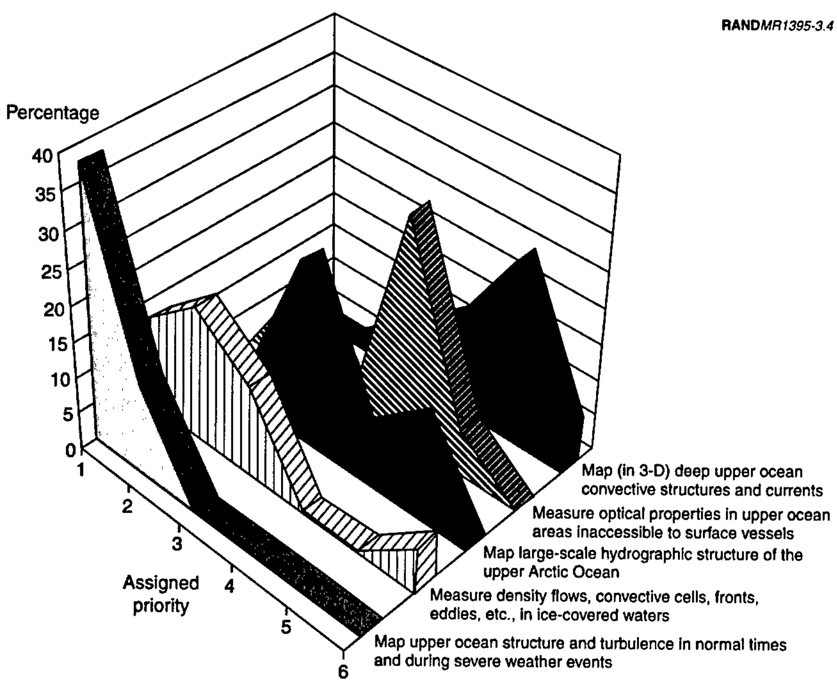

Figure 3.4—Subarea Priorities Within Physical Oceanography

As another example, with three ice science subareas identified a similar level of agreement was seen in the scientists' responses. All scientists agreed that mapping Arctic ice thickness, extent, structure, and roughness is the top priority in ice science (Figure 3.5). The large majority agreed that observing the ocean response to opening, closing, and advection at the ice edges is the second priority. This response was echoed in the subarea of near under-ice sampling of water properties. A similar majority agreed that this subarea is the third priority, with the balance assigning it second priority.

The individual science subarea objective prioritization was completed for each scientific field and is presented in the subsequent section on science mission profiles. All science subareas (mission objectives) were prioritized by specialists within the field using Groupware software.

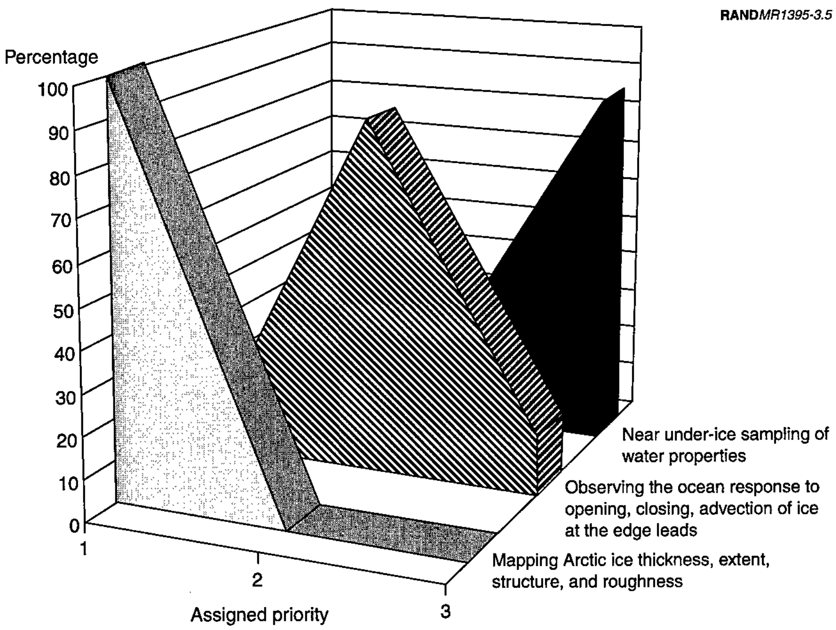

Figure 3.5—Assigned Priorities Within Ice Science

Capabilities. To bound the range of required top-level capabilities, RAND first chose a set of characteristics for examination. RAND developed the range of these characteristics based on discussions with scientists, ship designers, and experienced submarine operators. In addition, Naval Sea Systems Command (NAVSEA) presented as a catalyst for discussion a series of preliminary designs (see Appendix B). Each science area was reviewed in turn and assessments conducted of the range of the required capability or, if applicable, of the necessity for the capability on the vessel to execute a particular scientific mission. The capabilities under discussion were derived from the input of scientists executing missions, operator inputs, and ship and systems designers. The top-level capabilities examined included the following:

- Under-ice capability.

- Science team size/crew augment capacity.
- On-station research time available.
- Submerged speed available.
- Maximum vessel operating depth.
- Ability to employ remotely operated vehicles and autonomous undersea vehicles (ROVs/AUVs).

The result of this prioritization is shown in Figure 3.6. Preferences were sharply defined for the highest-rated top-level capabilities. The capability viewed as easiest to sacrifice was science team size.

These capabilities were then evaluated for each of the science missions. Capabilities important across a range of priority science mis-

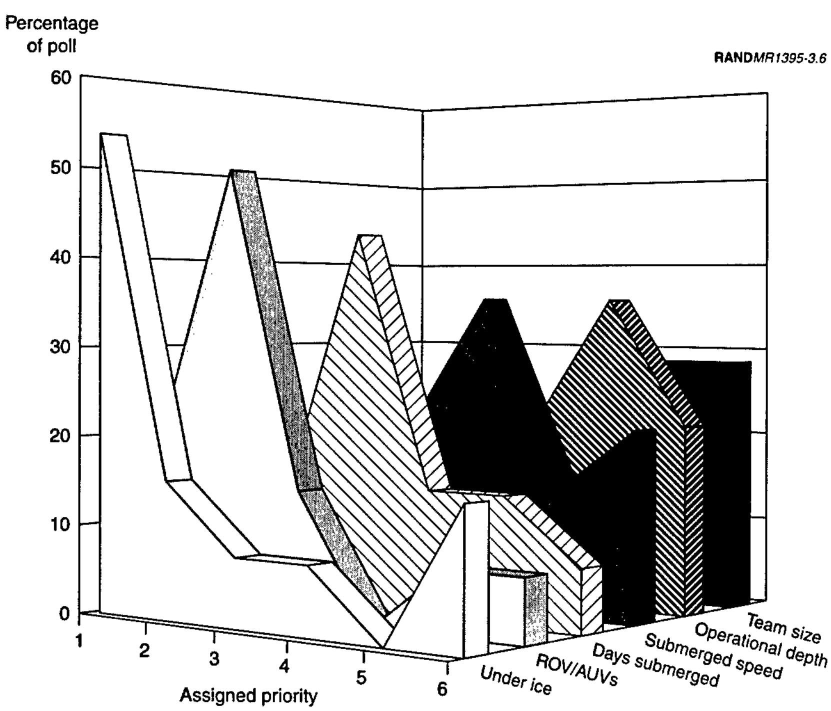

Figure 3.6—Top-Level Capabilities

sions become high-priority themselves. Scientists gave under-ice capability a high priority; in six of the nine science missions, scientists unanimously considered under-ice capability desirable. In all science missions except maritime archeology, virtually every one of the scientists judged under-ice capability to be a desirable feature (Figure 3.7).

The rankings shown in Figure 3.8 are consistent with the earlier view that the ability to operate ROVs/AUVs is important but not as important as under-ice capability. The ability to operate ROVs/AUVs would clearly increase the NR-2's effectiveness as a science platform, especially in the geology and geophysics and environmental science fields.

Scientists uniformly viewed at least 30 days of dedicated submerged time as the minimum adequate for science missions, with a 45-day

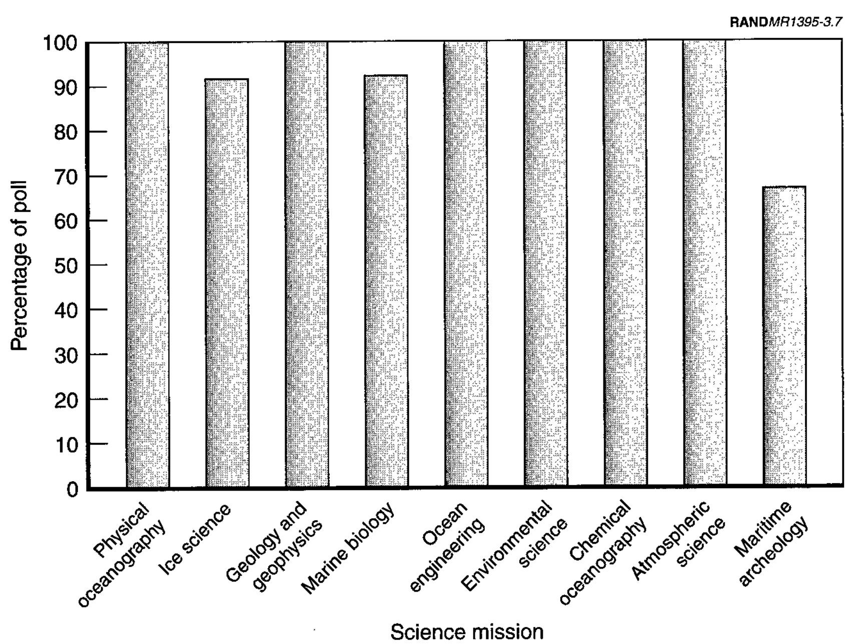

Figure 3.7—Under-Ice Requirement

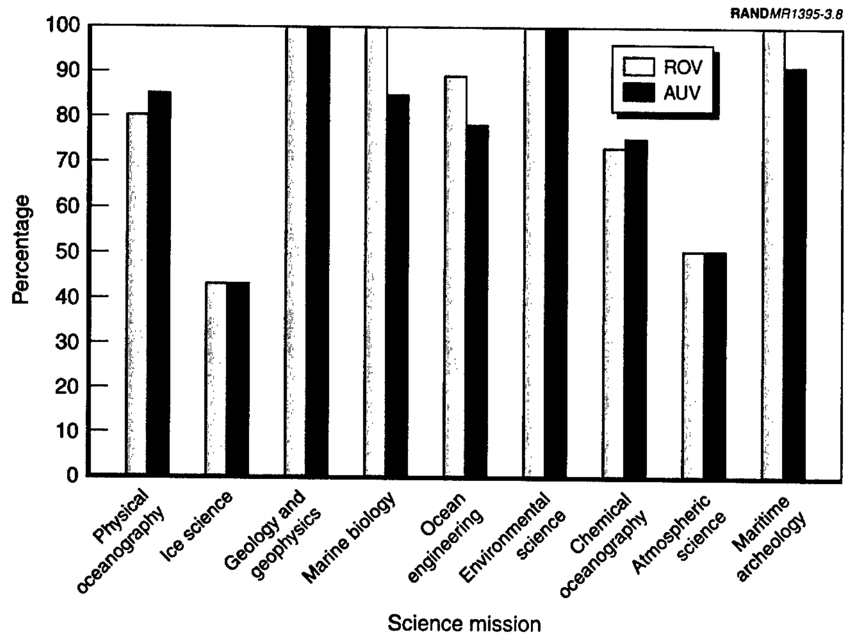

Figure 3.8—Need for ROV/AUV

capability for dedicated submerged research desired (Figure 3.9). If NR-2 will operate autonomously, these figures suggest that greater submerged endurance than that possessed by NR-1 will be required.[3]

An optimal speed range of 10 to 15 knots was established by the participants (Figure 3.10). Each scientific research area applied different criteria for determining the basis for necessary speed. For example, in the case of a research area that requires extensive survey, the criterion was track length over time. In the case of under-ice capability, for much the same reason, a good rate of speed was considered

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[3]In the later discussion of required speed, a collateral benefit of higher speed was its help in further ensuring efficient use of underway time—i.e., higher transit speed would help ensure less time lost to transit and more time available for on-station research.

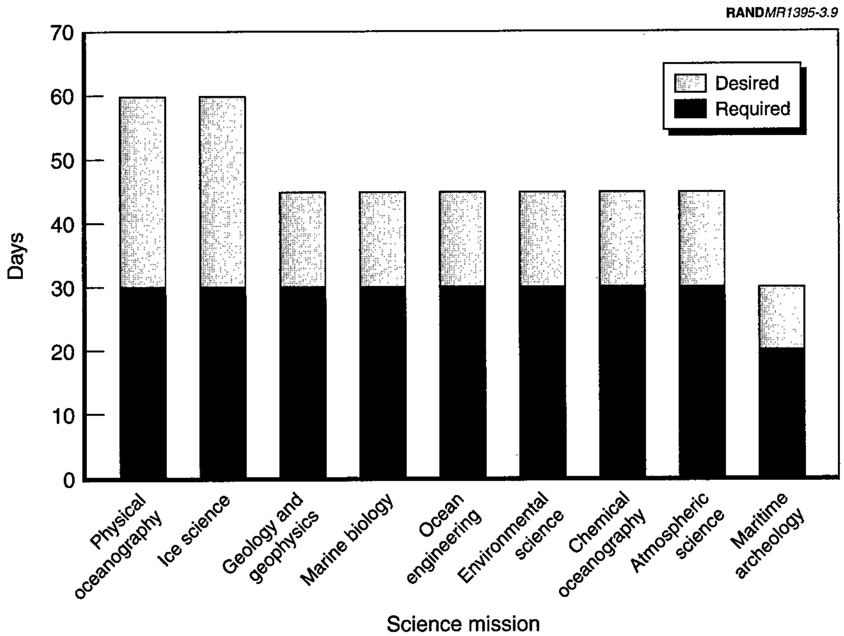

Figure 3.9—Submerged Research Time

essential to make under-ice capability most useful for overhead or under-keel survey.

As mentioned previously, scientists considered submarine maximum operating depth as a "mission" capability for the ship and ROV in combination. Scientists were clearly sensitive to cost/capability trade-offs with regard to depth in the submarine structure. In that regard, there was unanimity in that whatever could be achieved with ROVs should be, and submarine depth capability should be limited accordingly. This is reflected as well in the overall prioritization of capabilities reviewed earlier, in which submarine depth capability was second-lowest in priority.

Figure 3.11 reflects the scientists' judgments with regard to the required and desired operating depth capability ranges for science

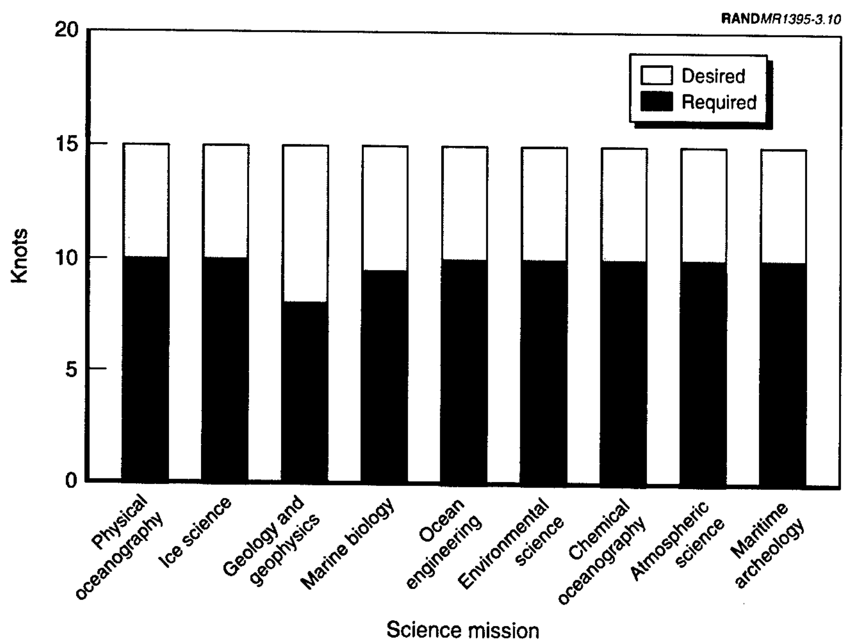

Figure 3.10—Submerged Speed

research. The depth ranges are somewhat intuitive with marine biology being the significant driver for greatest mission depth capability. For perspective in terms of accessible percentages and specific areas of the Earth, these desired depths must be viewed in conjunction with the Earth's hypsometry presented in Appendix F. As expected, shallower depth requirements are associated with the atmospheric and ice science mission areas.

Science team size was found to be difficult to project meaningfully by the experts. As in the past, actual team size would be likely driven by the details of the mission and space available. Also, it has been observed that science team size is driven by other ship capabilities. Finally, science team size was judged the characteristic experts were most willing to trade away. Some scientists added that it is not unlikely that in the future, depending on mission areas, science teams might be unnecessary.

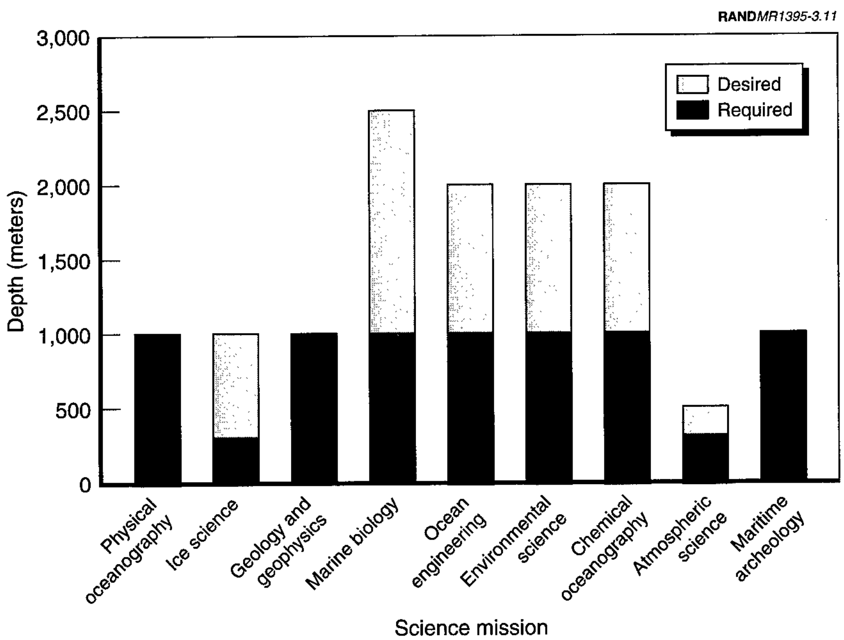

Figure 3.11—Operating Depth Capability

NR-2 MISSION PROFILES[4]

Mission profiling is presented for two purposes: First, profiling leads to a better understanding of the capabilities required for NR-2 to successfully accomplish a given mission. Second, the CONOP is to be used as an input for a follow-on AoA. Mission profiles were developed through reviews of NR-1 mission records and by review with scientists proficient in mission execution and with ship operators. This method of mission profiling should lead to a better understanding of the mission baseline to be used for comparing platforms in the AoA.

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[4]In addition to the mission descriptions and objects noted herein, additional insights can be gained by reference to http://128.160.23.54/product/pubs/medea/sci_utility.html#sea_ice.

Although presented separately here, NR-2 would be expected to be scheduled for completion of more than one mission type during any one underway period. In terms of CONOP, whenever possible, conjunctive scientific missions will be executed and data collected for several scientific mission areas, co-registered and concurrently evaluated. For example in SCICEX[5] 99, oceanographers eventually identified changes in water depth through monitored changes in the physical properties of collected ocean water samples. Capture of cross-correlated and co-registered parametric information offers the opportunity to better understand the interrelationships that exist in the ocean and affords the chance to detect changes in the oceans well before the changes take place. The following sections profile each science mission by prioritizing mission objectives and capabilities.[6]

Physical Oceanography Mission (Rank: 1) Description, Objectives, and Capabilities

Description. The physical oceanography mission is an overarching operation that seeks to capture in situ many physical parameters of the ocean and to co-register this information. The output of such an effort is a better understanding of the complexities of the oceans' physical properties and the development of more accurate models of the oceans.

Objectives. The physical oceanography mission objectives are in priority to:

- Map upper ocean structure (at near-synoptic, mesoscale, and basin-scale levels) and turbulence in normal times and during severe weather events.
- Measure density flows, convective cells, fronts, eddies, etc.

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[5]SCICEX is an under-ice science support mission undertaken by an Arctic-capable SSN (nuclear attack submarine).

[6]Capabilities noted here were determined by the inputs of qualified scientists, operators, and ship designers.

- Map large-scale physical structure of the upper Arctic Ocean, identifying frontal locations, water mass boundaries, changes in heat content, and location and structure of boundary currents.
- Measure optical properties in upper ocean areas inaccessible to surface vessels (under-ice and heavy weather).
- Map (in 3-D) deep upper ocean convective structure and currents.
- Provide movable platform for ocean acoustic tomography.

Capabilities. The following constitutes the list of NR-2 capabilities to execute the physical oceanography mission:

- Multipurpose acoustic suite[7]
- Launch, operate, and recover adjuvant vehicles/towed sensor arrays
- 3-D visual
- Under-ice capable
- Precise navigation[8]
- Standard external sensor installations
- Operations on or near the bottom
- In-situ water sampling
- Co-registration of scientific data
- External handling, segregated stowage, and excavation/burial
- Launch and monitor tethered/nonrecoverable sensors
- Uninterrupted/conditioned power
- Automatic depth control

[7]A multipurpose acoustic suite is understood to have the following systems: a high-resolution sonar for imaging the bottom and surface (including surface ice) ahead, a high-resolution sonar for imaging the surface and bottom above and below, and side-looking sonar for mapping the bottom. Such sonars are suitable for avoiding obstacles, tracking undersea mammals and fish, and surveying the bottom.

[8]For a definition of the requirements for "precise navigation," see p. 14.

- Communications.

Ice Science Mission (Rank: 2) Description, Objectives, and Capabilities

Description. The ice science mission will be conducted in the Marginal Ice Zone (MIZ) and beneath the Arctic sea ice. Its focus will be to define fundamental geophysics of the ice-covered Arctic and to ascertain the environmental changes occurring on and beneath Arctic sea ice and in the adjacent open ocean areas. Since the Arctic Ocean and adjacent seas are the major drivers of the world's ocean currents, and thus climate, the known changes in ice mass in the Arctic and the potential impact of these changes on the Arctic's role in global ocean current circulation and climate are of significant interest to the scientific community and the world's policymakers.

With respect to NR-2's execution of this scientific effort, the conduct of an ice science mission will require collection throughout the water column. Accordingly, operations at depths other than in close proximity to the sea ice bottom would be anticipated. Operating within this profile will lend itself to the conduct of conjunctive scientific missions envisioned by the scientific community and described in detail in other mission profiles.

Objectives. The ice science mission objectives are as follows:

- Map the thickness, extent, structure, and roughness of Arctic sea ice to assess any statistical changes.
- Observe the ocean response (optical, biological, physical, chemical) to evaluate the opening and closing of leads and advection of ice in the MIZ to determine the impact adjacent to the sea ice.
- Conduct sampling of near, under-ice water properties to assess the impact on the body of water beneath the sea ice from the gain or loss of ice mass.
- Employ special sensors to collect data on the geophysical character of the Arctic basin in areas not previously studied.
- Plant (and recover) upward-looking acoustic sensors to measure ice draft/mass/motion or ocean currents.

Capabilities. The following constitutes the list of NR-2 capabilities to execute the ice science mission:

- Multipurpose acoustic suite
- Launch, operate, and recover adjuvant vehicles/towed sensor arrays
- 3-D visual
- Under-ice capable
- Precise navigation
- Standard external sensor installations
- In-situ water sampling
- Co-registration of scientific data
- Launch and monitor tethered/nonrecoverable sensors
- Uninterrupted/conditioned power
- Automatic depth control
- Communications.

Geology and Geophysics Mission (Rank: 3) Description, Objectives, and Capabilities

Description. The geology and geophysics mission presents one of the more challenging operations that the NR-2 could undertake. Assuming NR-2's depth capability to be equal to or greater than NR-1's, 25 percent of the Arctic Ocean bottom would be immediately accessible. With adjuvant vehicles, the entire depth profile of the Arctic Ocean will be accessible to NR-2. This capability is of particular utility to explore not only the Arctic Ocean ridges/bottom topography, but also the ocean ridges throughout the world, which are under predominantly heavy weather and present a hazard to oceanography conducted from surface ships. Tectonic boundary areas particularly interest the scientific community.

Exploration of geophysical activities will be of significant importance in the future. The exploration and exploitation of methane hydrate fields (Dickens et al., 1997; Kvenvolden, 1988; Kvenvolden, 1993), for

instance, represent a research effort to which NR-2 could contribute. The task of detecting and mapping methane hydrates under Arctic sea ice or predominantly heavy weather regions could benefit from a platform like an NR-2, which can access these areas year-round.

Geology and geophysics is a "sensor intensive" activity from the perspective of the mission platform. Although some sensor systems would remain on board, offboard sensors on adjuvant vehicles, sensors on towed devices, or sensors planted on the ocean bottom by NR-2 in inaccessible areas in support of other geological programs would be major contributors to this mission. If NR-2 can carry the sensor to the theater of interest or an offboard unit can reach the area of interest, geology and geophysics collections will be made year-round, including the retrieval of bottom samples for laboratory analysis.

Objectives. The objectives of the geology and geophysics mission are as follows:

- Map and survey specific areas (e.g., gas hydrate fields, midocean ridges of the lower southern oceans, sites of recent volcanic eruptions, hydrothermal vents).
- Profile sub-bottom sediments.
- Measure multichannel seismic refraction/reflection.
- Co-measure gravity and bathymetry (from a high-stability platform).
- Map magnetic fields.
- Map hydrate occurrences in the sub-bottom.
- Deploy and recover, as prescribed, such ocean bottom sensors as seismometers in otherwise inaccessible areas.
- Conduct deep towed seismic surveys.
- Recover ocean bottom samples.
- Plant and recover bottom traps to collect biologic samples to (1) determine biological activity and (2) identify presence of contaminants (chemical/nuclear/heavy metals) in the bottom food chain (e.g., amphipods).

- Plant (and recover) upward-looking acoustic sensors to measure ice draft/mass/motion or ocean currents.

Capabilities. The following constitutes the list of NR-2 capabilities to execute the geology and geophysical mission:

- Multipurpose acoustic suite
- Launch, operate, and recover adjuvant vehicles/towed sensor arrays
- 3-D visual
- Under-ice capable
- Precise navigation
- Standard external sensor installations
- Operations near and on the bottom
- In-situ water sampling
- Co-registration of scientific data
- External handling, segregated stowage, and excavation/burial
- Uninterrupted/conditioned power
- Communications.

Marine Biology Mission (Rank: 4) Description, Objectives, and Capabilities

Description. Marine biology missions encompass research activities throughout the water column. Major global climate changes, such as El Niño and those occurring in the Arctic, have altered the world oceans from the surface to the bottom. Consequently, the impact on marine life is of great interest and concern to marine biologists. Given that the world's oceans are a major food source, the potential alteration of marine life must be investigated and characterized.

The exchange between shallow and deep ocean waters affects life throughout the water column. As a result, the marine biology mission dictates the capability to reach into the deep ocean floor as well as near the surface to complete a comprehensive evaluation of the

impact on marine life. In some scenarios, this requires missions in ocean environments into which only a submersible platform may venture, including Arctic regions and areas of heavy weather.

In addition to effects of global climate change, marine biology missions with NR-2 can contribute significantly to the exploration of fauna living in extreme environments in the deep sea, including hydrothermal vents and a variety of seep environments, where primary productivity is based on chemosynthesis rather than photosynthesis. A number of these environments occur beneath ice in the Arctic or at high latitudes in the southern hemisphere, where heavy seas preclude conventional deep-submergence activities.

Marine biology missions will require a diverse suite of sensors, mapping capabilities, and sampling devices. Both onboard and offboard features will be required to sample the full water column. Samples to be collected include water and organisms from the water column as well as samples of benthic organisms and substratum. Certain biological observations, such as those that assess biological response to global climate change, may need to be taken periodically, over intervals of years, to track the trends of the changes.

Objectives. The objectives of the marine biology mission are as follows:

- Conduct close, stationary, and prolonged observations of benthic habitats over large areas to map and characterize them.
- Investigate the effects of anthropogenic (man-made) structures and material deposition on benthic communities at 1,000 meters to 2,500 meters water depth.
- Investigate deepwater (below 2,000 meters) species and their value in commercial fisheries.
- Conduct census of marine mammals using onboard/offboard sensors.
- Investigate foraging ecology of deep-diving cetaceans to characterize long dives and understand interactions with their prey.
- Map (in 3-D) distribution of pigments (e.g., chlorophyll) in mesoscale ocean structures, such as eddies and fronts, using fluorescence and water sampling.

- Measure impact of severe weather systems on upper ocean biosphere.
- Study biocomplexity and biogeography/biodiversity.
- Study productivity and nutrient cycling.
- Study evolution of marine communities (e.g., the relationships among whales, seeps, vent fauna).
- Study relationship between fine-scale physical structures (shear and stratification) and fine-scale biological distributions (phytoplankton and zooplankton).
- Study sea ice ecology.
- Conduct fish stock assessments in inaccessible areas.

Capabilities. The following constitutes the list of NR-2 capabilities to execute the marine biology mission:

- Multipurpose acoustic suite
- Launch, operate, and recover adjuvant vehicles/towed sensor arrays
- 3-D visual
- Under-ice capable
- Precise navigation
- Operations on or near the bottom
- In-situ water sampling
- Co-registration of scientific data
- External handling, segregated stowage, and excavation/burial.

Ocean Engineering Mission (Rank: 5) Description, Objectives, and Capabilities

Description. Ocean engineering is the application of technology to perform specific tasks in the water column and on or near the bottom. While by definition ocean engineering is not a scientific discipline, it can be, and most likely will be, an integral part of every sci-

entific mission. It will assist in the planning and preparation, in the outfitting, and in the conduct of tasks, particularly when employing devices that are new, complex, and fragile.

Objectives. The objectives of the ocean engineering mission are as follows:

- Ocean search and recovery, usually small objects from deep waters or relatively larger objects from shallow waters.
- Salvage and wreck clearance, usually defined as the recovery or clearance of ships or other large, valuable objects. Salvage implies residual value; clearance implies little or no residual value.
- Data collection for the purpose of designing underwater structures, moors, anchors, etc.
- Installation, servicing, and maintaining underwater structures and systems, those suspended in the water column, and those on the bottom.
- Supporting other commercial operations, such as offshore oil exploration, drilling, production, storage, and transport; ocean mining; and cable and pipe laying.

Capabilities. The following constitutes the list of NR-2 capabilities to execute the ocean engineering mission:

- Multipurpose acoustic suite
- Launch, operate, and recover adjuvant vehicles/towed sensor arrays
- 3-D visual
- Under-ice capable
- Precise navigation
- Standard external sensor installations
- Operations on or near the bottom
- In-situ water sampling
- External handling, segregated stowage, and excavation/burial.

Environmental Science Mission (Rank: 6) Description, Objectives, and Capabilities

Description. An environmental science mission will focus on capturing the environmental impacts of human actions on the oceans and in littoral regions. As such, it will likely be performed in close proximity to populated landmasses or areas of the ocean where man has elected to use the ocean as a "dumping ground" for various wastes, including hazardous wastes. It is reasonable that the environmental science collection plan will require NR-2 to meet speed, depth, and track length plans to maximize the product of the operation.

The impact on the ocean may start well inland along a river into which various elements are dumped or naturally flow. Consequently, the environmental science mission may be conducted in close proximity to the outfall of such rivers—in shallow waters—and therefore would take advantage of a "near" or "on the bottom" capability. This would offer the potential to study the fate and the impact of persistent organic pollutants, heavy metals, and radionuclides in areas of terrestrial runoff and relating to current flow, water structure information, and sedimentation.

Objectives. The objectives of the environmental science mission are as follows:

- Survey and monitor the results of past waste dumping sites.
- Characterize future hazardous waste disposal sites (including nuclear waste).
- Perform multidisciplinary studies in marine sanctuaries and marine protected areas.
- Assess changes in the overall health of the marine environment.
- Study the fate and the impact of persistent organic pollutants, heavy metals, and radionuclides on the marine environment.
- Gather current flow and water structure information as it relates to sedimentation.

Capabilities. The following constitutes the list of NR-2 capabilities to execute the environmental science mission:

- Multipurpose acoustic suite
- Launch, operate, and recover adjuvant vehicles/towed sensor arrays
- 3-D visual
- Under-ice capable
- Standard external sensor installations
- Operations on or near the bottom
- In-situ water sampling
- Co-registration of scientific data
- External handling, segregated stowage, and excavation/burial
- Launch and monitor tethered/nonrecoverable sensors
- Uninterrupted/conditioned power
- Automatic depth control.

Chemical Oceanography Mission (Rank: 7) Description, Objectives, and Capabilities

Description. The chemical oceanography mission meets the science requirements to understand the chemical interactions occurring in the world's oceans. It focuses on complex chemical activities that take place from the ocean's bottom up to and including the sea-to-atmosphere interface. It measures primary, secondary, or further derivative ocean chemistry signals, which are indicative of in-situ events not readily evident.

Chemical oceanography is a sensor-intensive activity as viewed from the perspective of the mission platform. If NR-2 can carry the sensor to the sample area of interest or an embarked ROV/AUV with integrated sensor package can reach the sample area of interest, chemical oceanography collections can be made, including the safe retrieval of samples for further laboratory analysis.

Objectives. The objectives of the chemical oceanography mission are as follows:

- Determine water mass age, trajectories, ocean ventilation, source/evolution of Arctic waters, and pollution assessment, using trace sampling.
- Measure organic compounds in situ from the bottom to the surface to determine the distribution of biological activity and the biogeochemical processes.
- Measure ocean nutrients and pigments to assess biological productivity.

Capabilities. The following constitutes the list of NR-2 capabilities to execute the chemical oceanography mission:

- Multipurpose acoustic suite
- Launch, operate, and recover adjuvant vehicles/towed sensor arrays
- 3-D visual
- Under-ice capable
- Precise navigation
- Standard external sensor installations
- Operations on or near the bottom
- In-situ water sampling
- Co-registration of scientific data
- External handling, segregated stowage, and excavation/burial
- Launch and monitor tethered/nonrecoverable sensors
- Uninterrupted/conditioned power
- Communications.

Atmospheric Science Mission (Rank: 8) Description, Objectives, and Capabilities

Description. Dynamic environmental interactions over the oceans range from beneath the ocean bottom to well into the Earth's atmosphere. The scientific community views this spectrum as one con-

tinuum for exploration and study. Interactions at the ocean surface—water or ice—with the atmosphere above are of great interest. It is desirable to measure the energy exchanges—for example, physical and chemical—between constituents of the ocean and the atmosphere above it. There is consensus that this "column of interest" must be studied in a collaborative manner to better understand the global changes being observed today and to better predict future global climate changes.

Ocean currents in the Arctic and near-Arctic region drive global ocean circulation. The northern oceans and the atmosphere above them represent a prime area for atmospheric science research. Likewise, the open oceans in northern latitudes are a region of heavy weather, wherein turbulence fosters significant interaction at the ocean/atmosphere interface. The presence of cyclones/hurricanes in the central and tropical latitudes creates additional research opportunities during heavy weather. Finally, man-made turbulence along global merchant shipping lanes is of increased interest to better understand the impact mankind may be having on the interplay between the oceans and the atmosphere.

Objectives. The objectives of the atmospheric science mission are as follows:

- Deploy buoys, ice penetrating sensors, and any other sensory devices to monitor interactions at the sea-air or ice-air interface.
- Within the constraints of ship safety, capture in-situ environmental conditions for data collection. This is anticipated to take place either under sea ice or heavy weather, including hurricanes, by the host platform.
- Measure and record deep ocean parameters during climate events (e.g., El Niño, fronts, eddies, and "conveyor belt" currents) concurrently to develop a full vertical profile "under" the sea-air interface.

Capabilities. The following constitutes the list of NR-2 capabilities to execute the atmospheric science mission:

- Multipurpose acoustic suite

- Launch, operate, and recover adjuvant vehicles/towed sensor arrays
- 3-D visual
- Under-ice capable
- Precise navigation
- Standard external sensor installations
- Co-registration of scientific data
- Launch and monitor tethered/nonrecoverable sensors
- Uninterrupted/conditioned power
- Automatic depth control
- Communications.

Maritime Archeology Mission (Rank: 9) Description, Objectives, and Capabilities

Description. NR-1 has been called on repeatedly to perform maritime archeology missions. It is anticipated that NR-2 would conduct similar operations. Although maritime archeology might be considered a "shallow water" effort, the capability to conduct "deep water" search and recovery in support of maritime archeology allows for exploration along ancient trade routes, which traversed deep waters.

Although considered to be operations focused primarily on discovery of artifacts and sites of past human presence, a maritime archeology mission can provide inferred information about the surroundings of the inhabitants. When one considers that detailed records regarding temporal variations that affect mankind were not kept as today, one is challenged to develop a picture about the manner and surroundings in which humans lived. When compared with the knowledge we are gathering today—for example, global climate changes and the impact they may be having on mankind—scientists are able to draw some comparisons with the findings of the past. With this information, a mosaic of weather over thousands of years may be reconstructed and the related impacts, such as health effects, better understood.

Objectives. The objectives of the maritime archeology missions are as follows:

- Search for archeological sites and map them in situ.
- Recover objects (excavating them if necessary).

Capabilities. The following constitutes the list of NR-2 capabilities to execute the maritime archeology mission:

- Multipurpose acoustic suite
- Launch, operate, and recover adjuvant vehicles/towed sensor arrays
- 3-D visual
- Under-ice capable
- Precise navigation
- Standard external sensor installations
- Operations on or near the bottom
- External handling, segregated stowage, and excavation/burial
- Launch and monitor tethered/nonrecoverable sensors
- Automatic depth control.

SCIENCE SUMMARY

Figure 3.12 and Table 3.1 summarize the prioritized capabilities required to support the science missions profiled in this chapter. In the figure, capabilities are ranked by the number of scientific missions affected by that capability. For example, all scientific missions would benefit from the incorporation of a multipurpose acoustic sonar suite. On the other hand, only one (marine biology) would benefit from extending the NR-2 depth capability to 2,500 meters. The table summarizes capability requirements more precisely.

CONOPs

CONOPs for execution of these missions are included in Appendix C.

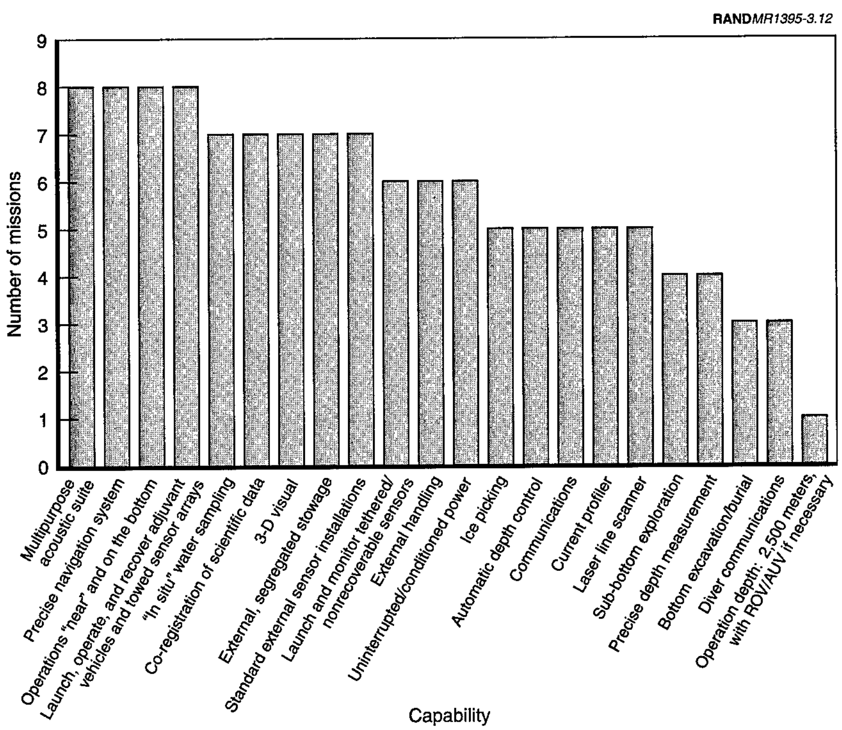

Figure 3.12—Capabilities to Supported Missions

Table 3.1

Capabilities to Requirements by Science Mission

Capability	Physical Ocean	Ice Science	Geol and Geophys	Marine Biology	Ocean Eng	Environ-mental Science	Chemi-cal Ocean	Atmo-spheric Science	Mari-time Arch	NR-1 Ops[a]
Ice picking	X	X		X			X	X		
In-situ water sampling	X	X	X	X	X	X	X			
3-D visual[b]		X	X	X	X	X			X	X
Multipurpose acoustic suite[c]	X	X	X	X	X		X	X	X	
Launch and monitor teth-ered/nonrecoverable sensors	X	X	X			X	X	X		
Launch, operate, and recover adjuvant vehicles and towed sensor arrays[d]	X	X	X	X	X	X	X (down to 6,000 meters)	X		
Co-registration of scientific data[e]	X	X	X	X		X	X	X		
Operating depth: 2,500 meters, with ROV/AUV if necessary				X						
Standard external sensor installations[f]	X	X	X		X	X	X	X		
Automatic depth control	X	X				X		X	X	
Precise navigation system[g]	X	X	X	X	X		X	X	X	
Communications[h]	X	X	X				X	X		
Precise depth measurement	X	X		X			X			
Uninterrupted/conditioned power	X	X	X			X	X	X		

Table 3.1—continued

Capability	Physical Ocean	Ice Science	Geol and Geophys	Marine Biology	Ocean Eng	Environmental Science	Chemical Ocean	Atmospheric Science	Maritime Arch	NR-1 Ops[a]
Current profiler	X	X			X	X	X			
Laser line scanner		X	X		X				X	X
Sub-bottom exploration[i]			X		X				X	X
External handling[j]			X	X	X	X			X	X
External, segregated stowage	X		X	X	X	X	X		X	
Bottom excavation/burial			X		X				X	
Operations on or near the bottom	X		X	X	X	X	X		X	X
Diver communications					X				X	X

[a]Historical operations took place almost exclusively on or near the ocean bottom. Little information afforded the opportunity to evaluate NR-1's capability near the surface or in the water column.

[b]Includes illumination and sail-mounted camera.

[c]This suite would include the following features: forward-upward/forward-downward looking; vertically upward and vertically downward looking; (SWATH/profiler); side looking. Used for obstacle avoidance, mammal/fish tracking, and measurement.

[d]"Operating" includes docking/recharging-replenishing an energy source/reprogramming/downloading data/etc.

[e]Includes voice-recording feature to correlate with scientific data gathering.

[f]Includes external mountings, electrical hull fittings capable of passing maximum data/electrical power from/to a sensor/scientific package, external appendage design, and protective features that have no impact on NR-2's standard operational procedures.

[g]Requirements for precise navigation are defined by the tasks of locating an object with a known position or recording the position of an object so it can be subsequently relocated. Precise navigation is also important when operating in restricted waters.

[h]Monitor external communications without interrupting extended time on/near the bottom or in the water column.

[i]Gather scientific data/information under the ocean bottom.

[j]Including fine sensing, maximum degree of freedom, and damped feedback.

Chapter Four

MILITARY

MILITARY MISSIONS

Potential military missions were derived from the results of two conferences.[1] In contrast to the science conference (discussed in Chapter Three), participants in these conferences included both military and civilian defense experts. The most significant difference in attendance was the presence of substantial number of submarine design experts[2] to inform the discussion of capabilities, allowing the conference to focus on submarine design "drivers"[3] as a result.

To provide first-order insight into the potential military missions of a replacement platform for the NR-1, a "context" was established in the future 2015–2050 time frame, in which such a platform would likely be made available to the national command authorities (NCA) and theater commanders in chief (CINCs) for mission assignment. The value of a platform resembling NR-2 was viewed through this filter, which served as the catalyst for discussion and generation of potential mission profiles by conference participants. These were used in turn to define required supporting capabilities.[4]

[1]For an explanation of the voting process used at these conferences, see pp. 2–3, under the subhead, "Methodology and Limitations."

[2]These design experts represented NAVSEA as well as Electric Boat Corporation and Newport News Shipbuilding and Dry Dock company.

[3]"Drivers" refers to design characteristics that will have a large impact on the cost of a platform.

[4]Some discussions of capabilities focused only on those capabilities felt by scientists to be most important and omitted those felt to be of less importance. In some prioriti-

After completion of the first conference and review of results generated by that conference, a second conference was held to refine and review the NR-2 military missions from the initial military conference (see section on "Military Mission Refinement" below).

Results Summary

The military expert group at the first conference developed the following 11 mission categories along with mission profiles:[5]

- Systems Manipulation/Implantation/Control
- Recovering Objects
- Disabling/Removing Objects
- Forensics/Investigation
- Area Sanitization/Investigation
- Intelligence Surveillance and Reconnaissance (ISR)
- Support to Military Research and Development
- Gatekeeper
- Deep Diver/Special Operations Forces (SOF) Support
- Search and Rescue
- Undersea Logistics (Navy After Next concept).

During the second conference, a listing of candidate core NR-2 missions was generated by expanding, prioritizing, grouping, and down selecting from the mission list generated in the first conference. The process yielded the prioritized list of candidates for NR-2 core[6] military missions:

1. Selected Covert Operations

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zations, new capabilities were occasionally added in an exploratory effort but were then found to have negligible impact on expected cost.

[5]Details for profiles of all proposed military missions listed below are in Appendix E.

[6]Core missions are defined as those missions that would be assigned by the commander/NCA preferentially to the NR-2 above all other platforms.

2. Protection of National Assets on the Seabed
3. Intelligence Preparation of the Battlespace (IPB)
4. Forensics/Investigation
5. Expanded ISR
6. Offensive Information Operations
7. Defensive Information Operations

SUPPORT CONCEPTS

NR-1, the predecessor to NR-2, has not been heavily involved in military operations (individually or with support). Examining potential future military operations (2015–2050), the study considered three different support concepts (these are illustrated in Appendix G):

- **Fully autonomous operation.** In this mode the NR-2 would be designed for fully autonomous operation, as is any SSN. Among other considerations this would have the inherent implications on design for redundancy and speed-endurance in area-of-interest (AOI) trade-offs, which were not necessary in NR-1.
- **Operation in consort with an SSN.** This concept would provide SSN transport/tow to an AOI and escort/protection within an AOI as desired. The principal purpose of the SSN would be to minimize NR-2 time lost in transit and maximize mission time in AOI. Naturally, logistics and communication support is not as feasible in this mode of support.
- **Operation in consort with a surface support vessel.** This method of operation has proven particularly valuable in NR-1's operation on science and forensics/investigation missions (where sea conditions were accommodating for surface support). Surface support vessels can provide extensive logistics support to science missions both in crew relief and mission equipment support and enable transfer and offload of objects from NR-1. In the past, the surface vessel also provided tow and communications support when required/operationally desirable.

Although the concept of a dedicated surface ship "carry" to an AOI was discussed, it was not seriously pursued because of the current

limitations on overall Navy force structure. As with the NR-1, a single design can use all of these support concepts.

In evaluating the range of potential military missions over the life of the ship, 80 percent of the participants considered the fully autonomous concept of operation as the most appropriate as shown in Figure 4.1. None considered the surface ship support concept as appropriate if the NR-2 were to become more militarily mission assigned than the NR-1 was historically.

Some submariners considered an SSN escort preferable. This generally reflected the view that an SSN is capable of providing the required "transit" assistance to the NR-2.

Within these three CONOPs two other military design considerations were examined: quieting (magnetic and acoustic) and endurance.

Quieting. As seen in Figures 4.2 and 4.3, to reasonably bound quieting capability, three levels of acoustic and magnetic quieting were considered by participants: NR-1 level (no quieting), SSN-688-class

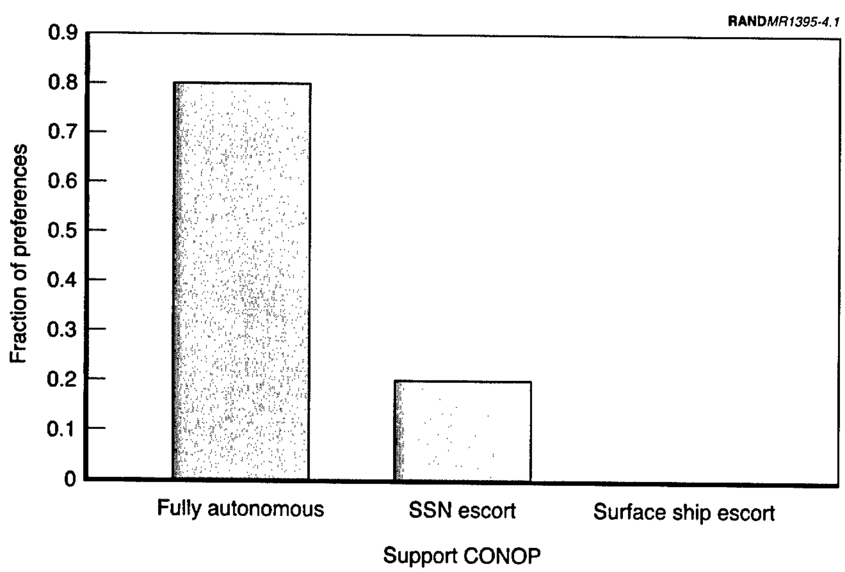

Figure 4.1—Support CONOP Preferences

level, which was used to represent 1970s–1980s' technology, and state of the art, used to represent the quieting available on the most advanced U.S. submarines. Best quieting was desired for the fully autonomous and the surface ship escort concepts. These choices are logical. Least quieting was acceptable in the case of SSN escort. Again, this was a logical choice. In the former case, NR-2 vulnerability in the area of interest will be a function of its own signature. In the latter case, participants' concern focused on the potential for adversary alert by the escort surface ship. In terms of the sonar equation, this effectively raises the noise recognition differential through alert to the possibility of an intruder—hence the greatest desire for the state-of-the-art acoustic quieting. A similar pattern is noted for magnetic quieting.

At the recommendation of NAVSEA 05 and the other ship designers, the aforementioned capabilities were prioritized across the mission areas that clearly broke out as the top three future military mission categories for NR-2 (namely, recovering objects, system manipulation, and removing or disabling objects).

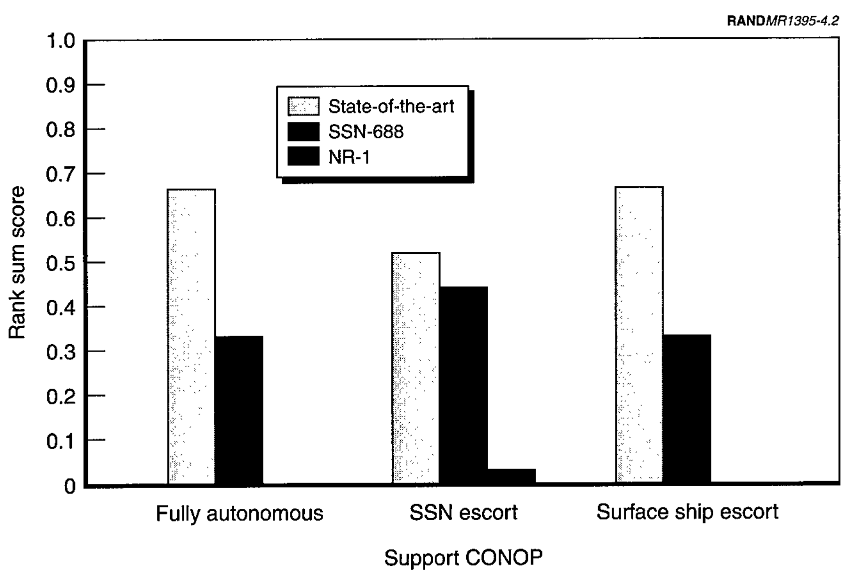

Figure 4.2—Acoustic Quieting Preferences by Support CONOP

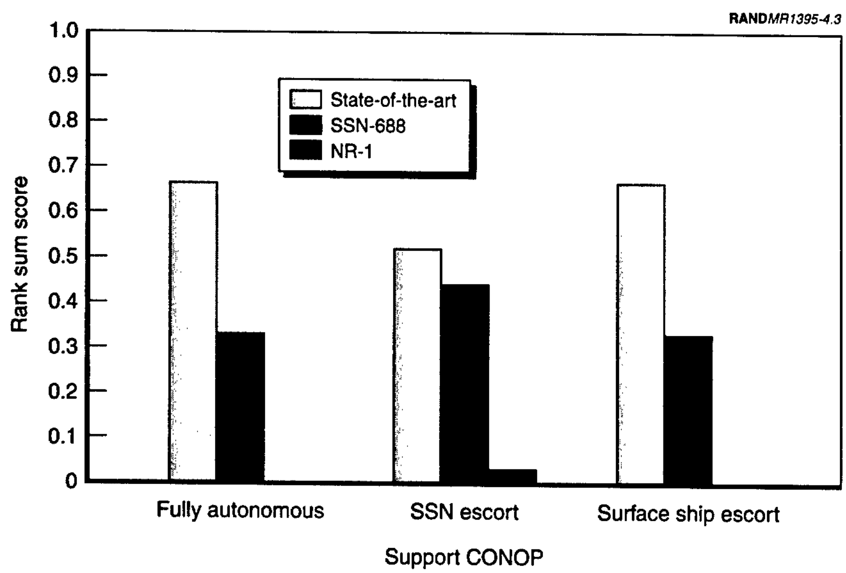

Figure 4.3—Magnetic Quieting Preferences by Support CONOP

Figure 4.6 reflects the prioritization of these capabilities across the higher-priority mission areas. Of note, the capabilities are uniformly weighted across all mission areas. Also of importance is the isolation of the bottom four capabilities (under-ice capability, redundancy, burst speed, and shock hardening).

MILITARY MISSION GENERATION

Before determining required capabilities, relative mission importance was assessed from four perspectives (Figure 4.4). All conference participants participated in these evaluations. Importance was first evaluated from two perspectives: future mission importance and future mission likelihood. The product of these was considered to be the measure of expected value. Participants evaluated each mission based on the relative likelihood of occurrence in the period of interest. Next, the missions were compared on the basis of importance—that is, if this mission were to be assigned by the NCA

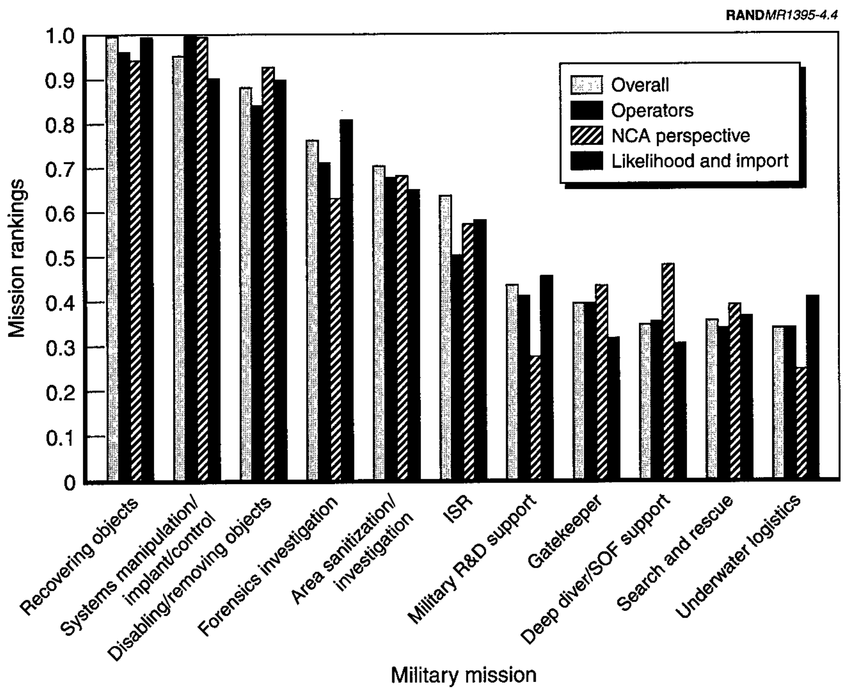

Figure 4.4—Mission Rankings

or military commander, how damaging would it be if the mission were not executed correctly. The combination of these two evaluations is reflected by the black bars in Figure 4.4. The striped bar "NCA perspective" reflects the participants' evaluation of the relative importance that the NCA would place on the mission capabilities attached to the NR-2. The "Operators" bar reflects the view that those participants with extensive operational military experience had of the priority of NR-2's mission capabilities. The "Overall" bar reflects the overall ranking of NR-2 missions—that is, across the future landscape, the priorities of missions likely to be assigned to the NR-2 during its lifetime. In effect, this reflects participants' views of the mission's priorities the sponsor should establish for NR-2.

Broad consistency in rankings is clear in Figure 4.4. The most noteworthy result of this ranking process is that regardless of which of the

four ways the survey was posed or to whom it was posed, six missions (recovering objects, systems manipulation, disabling objects, forensics investigation, area sanitization, and ISR) were *always* ranked above the other missions. Viewed from a different perspective, the missions of military R&D support, gatekeeper, deep diver/SOF support, search and rescue, and underwater logistics were *always* ranked below the other missions. The result of this schism in the mission set is a "break" in the ranking system between the ISR and R&D support. Also of note, the top missions were directly related to the NR-2's projected ability to operate on or near the bottom; the lower-ranked missions did not mandate that capability.

The consistency in Figure 4.4 shows that a rank sum can be applied to the 11 missions to achieve an overall ranking, shown in Figure 4.5, which indicates the break between ISR and military R&D support.

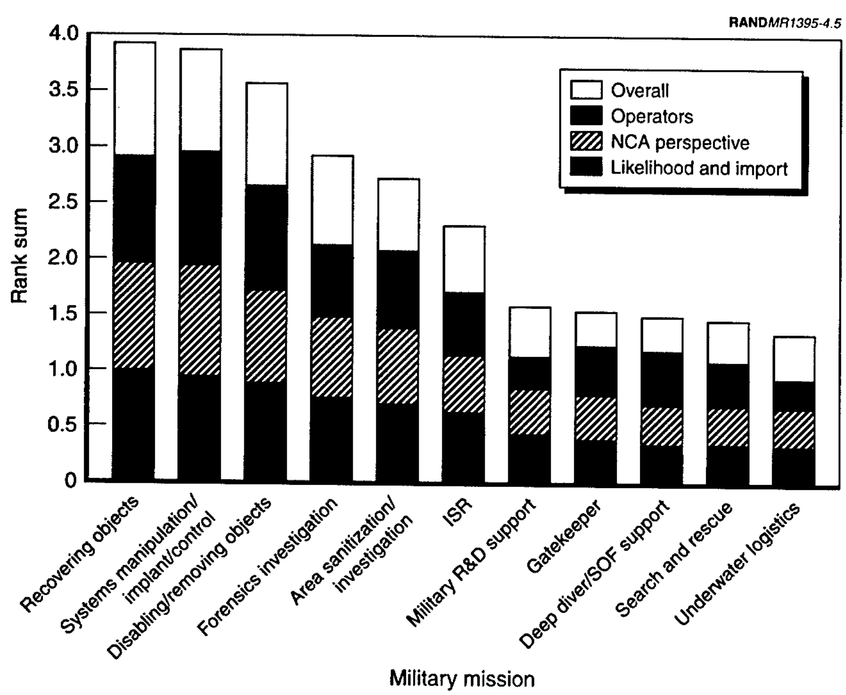

Figure 4.5—Rank Sum Mission Ranking

The missions of recovering objects and systems manipulation/implantation/control are functionally tied for higher rank. Underwater logistics was generally ranked last and in rank sum is last. This was likely due to three main factors. First, the inability to articulate the mission well because, as a Navy After Next (NAN) concept, it remained embryonic and ill-defined both in tangible operational requirement and capability—hence, mission—during the conference. Second, little in the title commended itself to the NR-2 as a deep submersible as an assigned vehicle for execution. Third, implicit in the mission of underwater logistics were requirements for speed and size orthogonal to other mission capabilities for NR-2.

At the request of NAVSEA, the three highest-priority missions were used to evaluate the following NR-2 design-driving capabilities:[7]

- Burst speed
- Transit speed
- Ingress/on-station/egress speed
- Test depth
- Acoustic quieting
- Magnetic quieting
- Ability to operate on or near the bottom
- Ability to reposition on or near the bottom
- Under-ice capability
- Ocean interface
- Offensive weapons
- Shock hardening
- Endurance.

Along with the above design-driving capabilities, three ancillary capabilities (payload, flexibility/adaptability, and redundancy) were

[7]Design-drivers were developed through discussions with ship designers. Definitions of these drivers can be found in Appendix D.

also selected for examination in the context of the three highest-priority missions. Their relative ranking can be seen in Figure 4.6.

Because no objective and universal weighting scheme was readily apparent in this study, a uniform weighting scheme was employed with capabilities to get a first-order insight into relative capability. As noted above (in footnote 4), some discussions of capabilities focused only on those capabilities felt by scientists to be the most important and omitted those thought to be of lower importance. In some prioritizations, new capabilities were occasionally added in an exploratory effort but were then found to have negligible impact.

The participants and designers discussed the concept of modular design at length. Rather than listing modularity as an ancillary capability or a full capability, designers maintained that future flexibility or adaptability would be achieved in the most cost-effective manner and in fact, modularity would be a design result as appropriate based on these overarching considerations.

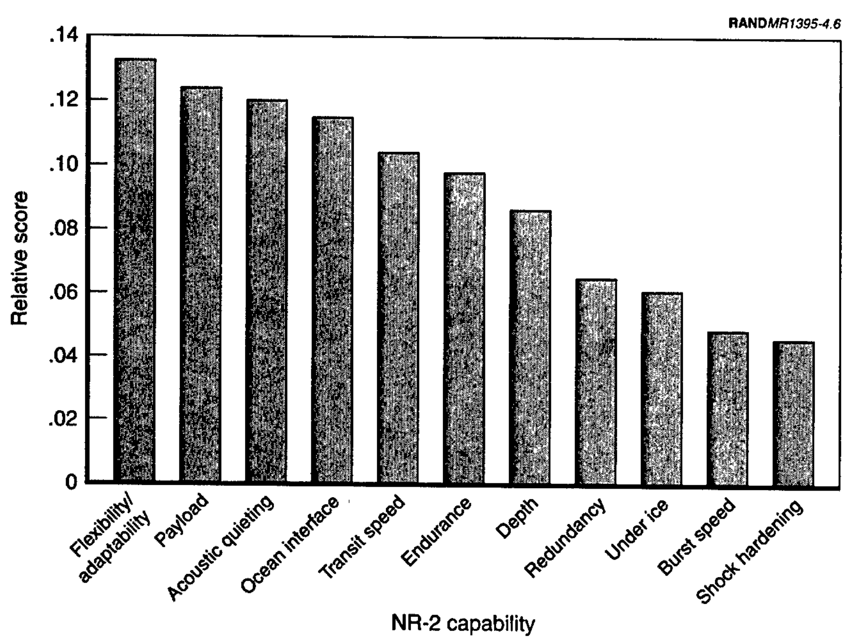

Figure 4.6—Capabilities Ranking

MISSION RANKING CAPABILITY IMPLICATIONS

The preceding paragraphs discussed the methods used for obtaining the required mission sets for a replacement platform for the NR-1 and the methods used to prioritize those missions and thereby reflect the weight or impact that the need to accomplish those missions should have on the capabilities incorporated into the NR-2.

Looking back more closely at Figure 4.4, however, allows missions to be segregated into two broad categories, those of likely *high* future *import* from the NR-2 (for our purposes those missions always grouped as the top five missions) and those of *low* likely future *import* from the NR-2 (for our purposes those missions always grouped as the bottom five missions).

Table 4.1 summarizes values derived for design-driving capabilities required for the identified military missions. From the viewpoint of

Table 4.1

Required NR-2 Capabilities

Capability	Value
Flexibility/adaptability	Highest priority
Payload	Second highest priority
Acoustic quieting	SSN-688 to state of the art[8]
Large ocean interface	Essential
Transit speed	15–20 knots
Endurance	30–45 days
Depth	500–1,000 meters with adjuvant vehicle 1,000 meters without adjuvant vehicle
Redundancy	Low priority
Under ice	Not required
Burst speed	15–20 knots
Shock hardening	Lowest priority

[8]Figures 4.2 and 4.3 suggest that state-of-the-art quieting was distinctly preferred but was not clearly regarded to be required in discussions with cost considerations ignored. In light of the upcoming AoA, ruling out the less-expensive SSN-688 quieting would seem premature.

capabilities to be included on the NR-2, it is noteworthy that one capability set will satisfy all the needs to accomplish the high-import missions. Said differently, this method of mission ranking allowed visibility into like groupings of mission sets, hence into the drivers of like capability requirements and like concepts of operation.

CONCEPTS OF OPERATION

Concepts of operation for execution of these mission profiles are included in Appendix C.

MILITARY MISSION REFINEMENT

A second military conference was held to review and refine the NR-2 military missions from the initial military conference with a group of submarine operations experts over a greater range of potential submarine operations in support of the NCA, to prioritize these missions in the context of 2015–2050, and to determine NR-2 capability thresholds[9] and objectives[10] for core missions (again emphasizing cost-driving capabilities) and further to prioritize these capabilities across all missions.

The new set of NR-2 military missions accommodated all illustrative mission objectives from the first symposium. For example, the mission of recovering sensitive objects from crash/wreck sites (originally included in the manipulate/recover objects military mission category was now accommodated under forensics investigation).

To further prioritize NR-2 core military missions, the proposed missions were prioritized again by expected frequency of occurrence in the future and by the relative impact of mission failure on national security (should they be conducted). The product of these two mea-

[9]That minimum acceptable value that, in the user's judgment, is necessary to satisfy the need. If threshold values are not achieved, program performance is seriously degraded, the program may be too costly, or the program may no longer be timely (DoD, 1996).

[10]The value desired by the user that the program manager (PM) is attempting to obtain. The objective value would represent an operationally meaningful, time critical, and cost-effective increment above the threshold for each program parameter (DoD, 1996).

sures provides an overall evaluation of mission importance. Highest scores go to missions expected to occur relatively often and to be of relatively high importance, should they fail in execution, to national security. The output provides a weighting to be assigned to capabilities (supporting missions) being designed into the NR-2 in any cost-benefit trade-off process.

Conference participants were in strong agreement as to expected frequency of mission occurrence (Figure 4.7). The protection of national assets on the seabed mission, for example, was expected to occur most frequently or second most frequently by a clear majority of participants. At the other extreme, a clear majority ranked the covert operations mission last by expected frequency of occurrence. As a result, capabilities associated with the successful accomplishment of the protection of national assets on the seabed mission

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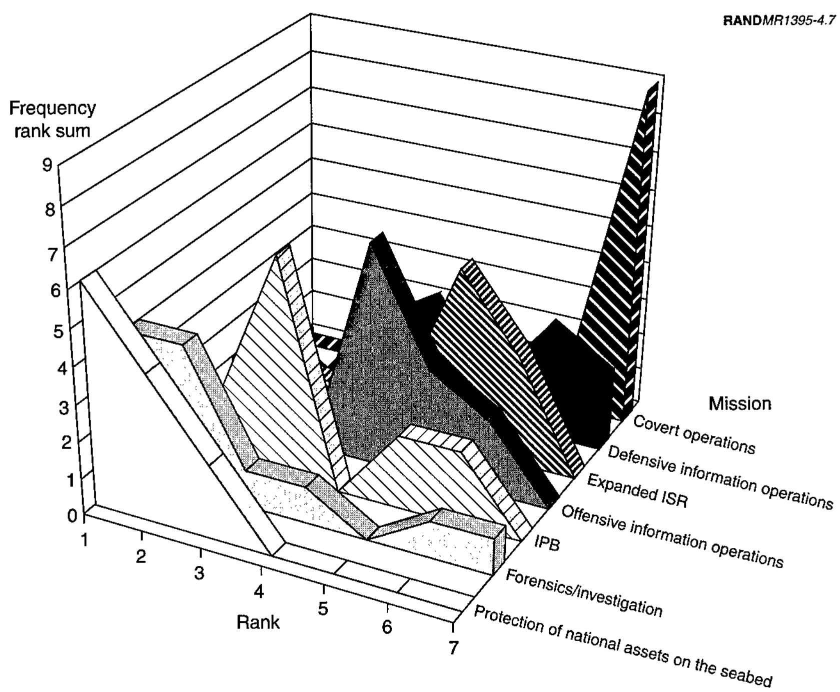

Figure 4.7—Mission Frequency Rankings

(essentially a defensive information operations mission) would logically be assigned a high priority in the design and trade study process. Conversely, those capabilities associated with covert operations when destruction of enemy assets was the objective (e.g., shock hardening) would receive lower priority.

Less uniformity is seen in ranking missions by their criticality to national security (Figure 4.8).

The results shown in the previous two figures are shown in rank sum form in Figures 4.9 and 4.10.

Combined, or overall, mission priorities are shown in Figure 4.11. These were generated as rank sums of priority assignments.

Core NR-2 military mission priorities in the 2015–2050 time frame stem from the NR-2 capability *set* differentiating it from other platforms. These are as follows:

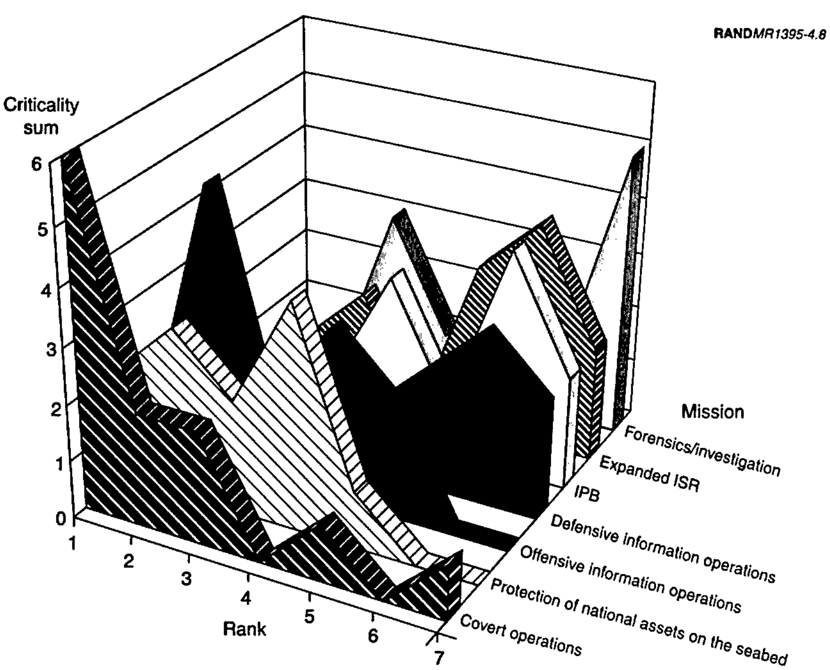

Figure 4.8—Mission Criticality Ranking

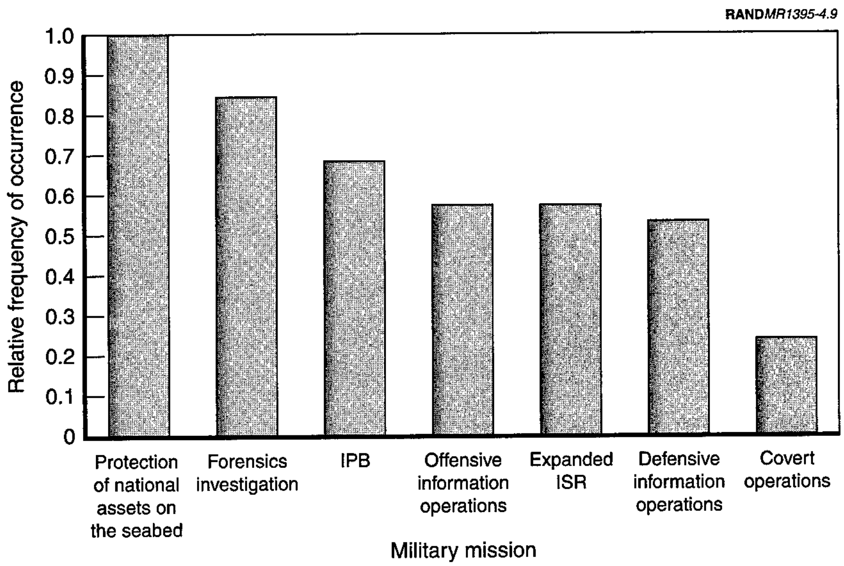

Figure 4.9—NR-2 Military Mission Expected Frequency of Occurrence

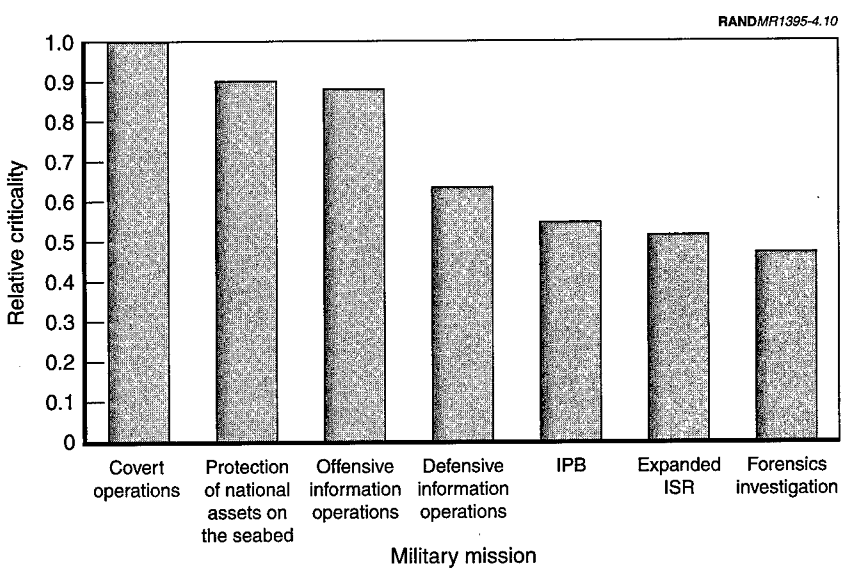

Figure 4.10—NR-2 Military Missions Expected Relative Criticality

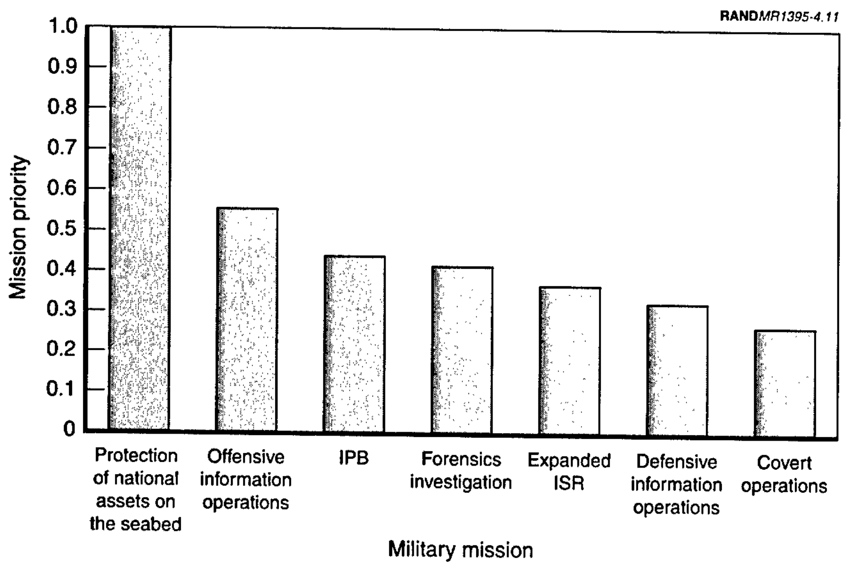

Figure 4.11—NR-2 Military Mission Priorities

- Ability to operate on the seabed.
- An ocean interface with the (implicit) ability to operate a state-of-the-art ROV that would allow it to extend its effective operating depth for object deployment, manipulation, or recovery below the test depth of the submarine.

The above mission scores strongly favor the protection of national assets mission, which was rated first in frequency of occurrence. There were two broad reasons for this ranking. First, as noted in Appendix I, in the past six years we have witnessed an exponential increase in international communications capacity stemming almost entirely from fiber optic cables laid on the seabed. Fiber optic capacity on the seabed now exceeds space capacity (by several orders of magnitude—space systems cannot be substituted for fiber optic systems on the seabed). Second, in the opinion of the participants, if built, the NR-2 would be the only dedicated national asset capable of both providing protection for the national information infrastructure on the seabed and deterring efforts to damage that infrastructure. This mission on a broad level is a national defensive

information warfare mission. Participants also recognized that it will only increase in value in the future, and in consideration of the threat, the threat against which it is conducted will likely also proliferate beyond the current targeting of military assets and improve in proficiency in the 2015–2050 time frame.[11]

The covert operations mission is scored last of these seven missions because of the expectation that the need to conduct it would be rare. The low score of the covert operations mission, combined with its distinctive mission profile, indicates that the consensus of those operational experts present was that NR-2's value would be in its design to operate and gather information and intelligence from the sea bottom, not in potential employment as a combatant. This is also consistent with three broader views noted by participants:

- The leverage of the NR-2 would be in completing the national "full spectrum" IPB capability.
- NR-2's potential as the transition continues to a cyberwar environment.[12]
- The availability to the NCA of many other (SOF) assets to accomplish "direct action" combat missions.

DESIGN-DRIVING CAPABILITIES

The design-driving capabilities derived in the first NR-2 military CONOPs conference carried over into the second conference. Again, they were:

- Burst speed
- Transit speed
- Ingress/on-station/egress speed
- Test depth

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[11]Participants carefully reviewed classified and unclassified assessments of existing and projected threats regarding this issue.

[12]Cyberwar is defined as conducting, or preparing to conduct, military operations according to information-related principles (Arquilla and Ronfeldt, 1997, p. 30).

- Acoustic quieting
- Magnetic quieting
- Ability to operate on or near the bottom
- Ability to reposition on or near the bottom
- Under-ice capability
- Offensive weapons
- Ocean interface
- Shock hardening
- Endurance.

(The scientific and military values for each of these design-driving capabilities is discussed in Chapter Five.)

Current operational submariners and former OICs of NR-1 provided inputs on capability objectives and thresholds for the NR-2 across the core mission areas addressed at the second military conference.

Their inputs are presented first by thresholds, then by objectives using natural groupings.

Speed Thresholds

Three speed regimes were prioritized by capability importance to operators. In priority order, these were transit speed, ingress/on-station/egress speed, and burst speed. Speed thresholds for NR-2 are shown in Figure 4.12 (with ingress/on-station/egress speed shown as "Speed in AOI" in the interest of brevity).

Transit speed in the range of 14 to 18 knots was preferred for two reasons: to allow prompt response to tasking and to maximize time on-station in the case of fully autonomous operations.

Speed in AOI of 8 to 10 knots was preferred, the better to allow adequate search speed with the presumptive sensor suite.

Burst speeds of 15 to 20 knots were preferred.

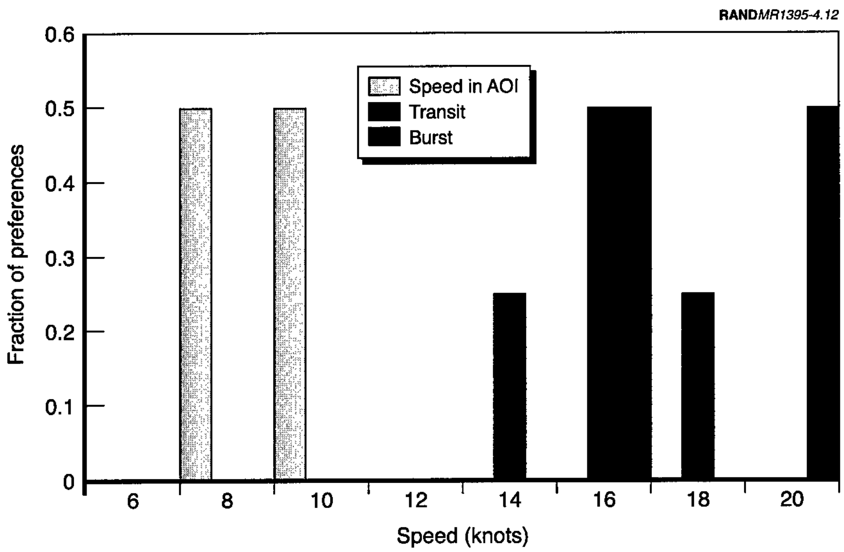

Figure 4.12—NR-2 Speed Thresholds

All speed preferences were consistent with a defensive operational philosophy exploiting low signatures and minimizing time on station. In essence, the NR-2 operational philosophy, if employed in covert military missions, would be to be responsive to tasking, ingress the area of interest quickly, complete the mission promptly, minimize time on station, leave no evidence of the mission, and exit quickly undetected ("get in, get out, leave nothing behind").

Depth

Figure 4.13 depicts preferred depth thresholds with and without an ROV/AUV.[13] A clear preference for a 1,000-meter test depth is evident. Such a depth would allow NR-2 to operate on or near the bottom over most continental shelves. Because one perceived advantage of the ROV/AUV has been its ability to go beneath a given level,

[13]As noted earlier, depictions of world hypsometry can be found in Appendix F.

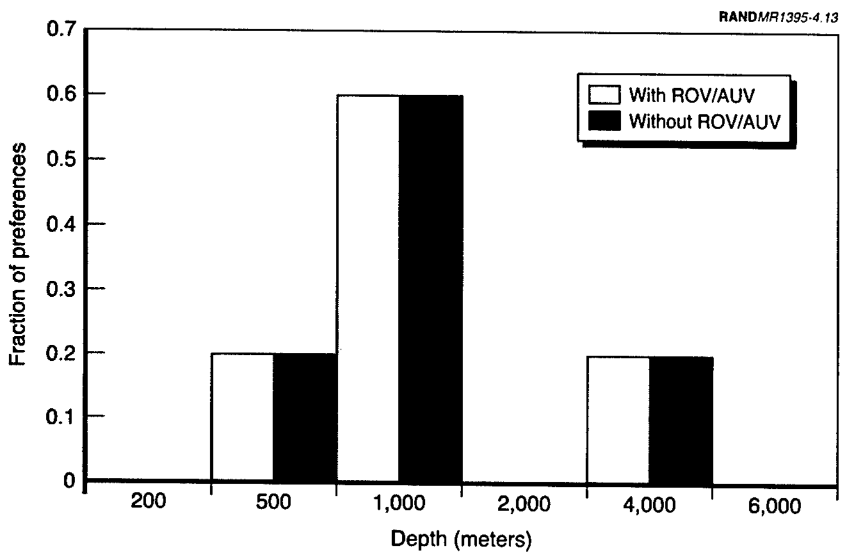

Figure 4.13—NR-2 Depth Thresholds

it is striking that preferred depth threshold was the same with and without an ROV/AUV. This is likely due to the current state of the art.

Current ROV/AUV limitations with regard to search capability and long-term navigational accuracy seemed to hamper military missions. It was noted that NR-2 operation on the bottom protects against threat weapons and that putting an ROV/AUV on the bottom offers no such protection. Skepticism also arose that ROVs/AUVs would have adequate bottom search/registration capabilities.

Signature

Acoustic and magnetic signatures were specified as state of the art. Acoustic quieting was desired for reducing encounter rates. Magnetic quieting would protect against mines and potential tripwires.

Bottom Operations

The need to operate on or near the bottom was unquestioned.

Under-Ice Capability

No need was seen for NR-2 to have the ability to operate under ice. This was consistent with the first NR-2 military mission conference findings, where under-ice capability was ordered last in desirability.

Offensive Weapons

No need was seen for providing NR-2 with offensive weapons. This was also consistent with the first NR-2 military CONOPs symposium.

Ocean Interface

The participants saw a clear need for an ocean interface. An ocean interface was a high priority in the first NR-2 military CONOPs symposium.

Shock Hardening

The participants were divided over the need for shock hardening; some agreed strongly with such a need but others were neutral on the need or felt that shock hardening was unnecessary. Overall, the participants leaned toward shock hardening. Response in the first NR-2 military CONOPs symposium was also divided but leaned away from shock hardening.

Endurance

Strong consensus was seen for 60 days of endurance for NR-2. This was felt to provide adequate time on station after a long transit. Participants in the first NR-2 military mission symposium generally favored a shorter endurance capability—in the range of 30 to 45 days.

Speed Objectives

NR-2 speed objectives for ingress/on-station/egress and transit speed objectives (Figure 4.14) resemble their corresponding speed thresholds. However, NR-2 burst speed objectives are significantly

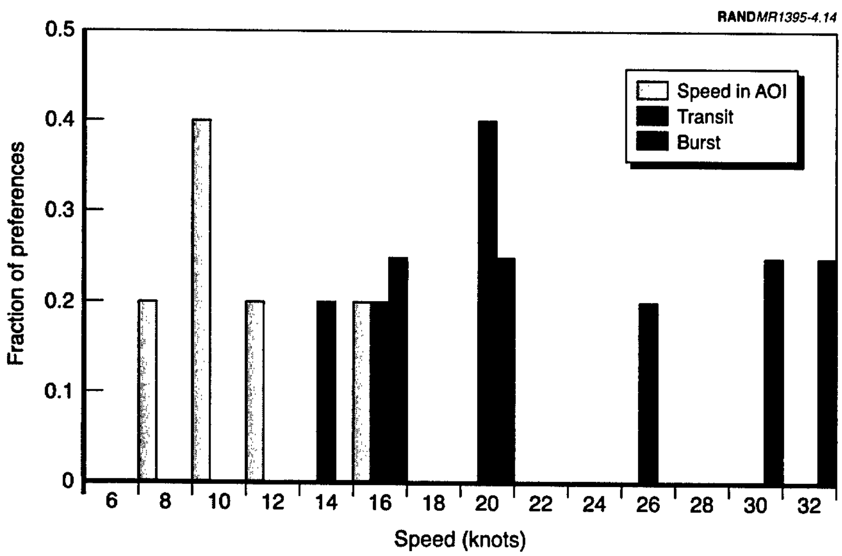

Figure 4.14—NR-2 Speed Objectives

higher than the burst speed thresholds (Figure 4.15). Again, ingress/on-station/egress speeds of about 8 to 12 knots are desired. Transit speeds of 14 to 26 knots are seen.

The disparity between NR-2 burst speed thresholds and objectives as viewed by the same operators is consistent with the low priority given to burst speed previously; a large increase in burst speed is required to produce an appreciable boost in mission effectiveness.

Depth Objectives

NR-2 test depth objectives with and without an ROV/AUV are shown in Figure 4.16. Other than one outlying 6,000-meter test depth, they are similar to NR-2 depth thresholds seen previously.

MISSIONS

The second military conference confirmed and expanded the mission objective set from the first military conference. The mission

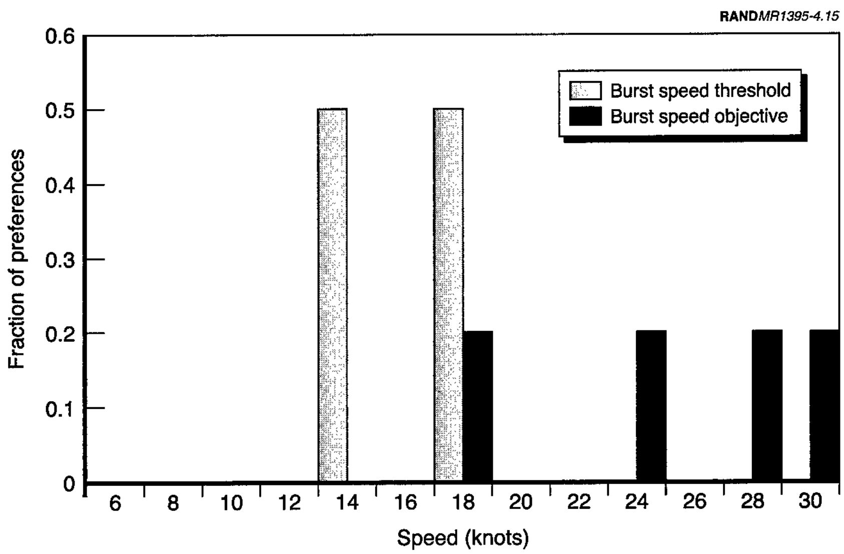

Figure 4.15—NR-2 Burst Speed Thresholds and Objectives

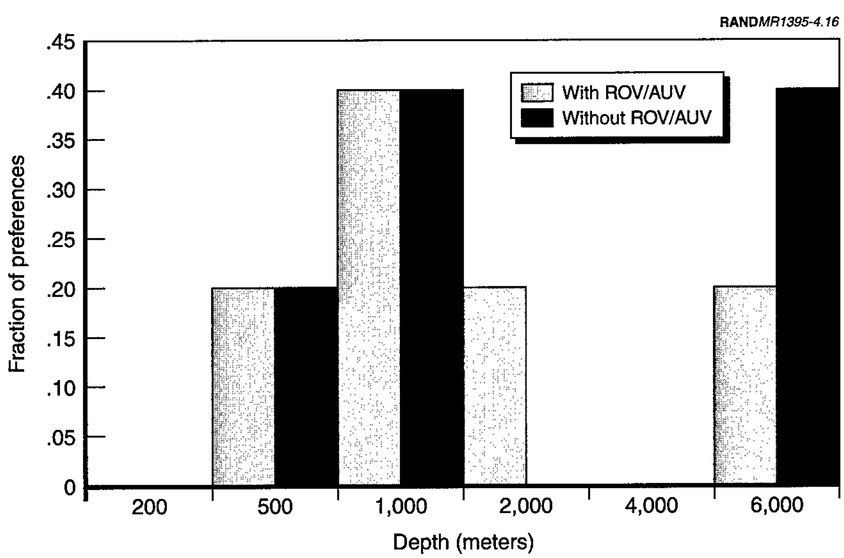

Figure 4.16—NR-2 Depth Objectives

niche of the NR-2 was confirmed as missions derivative from the NR-2 capability set of bottom operations coupled with manipulation capabilities and the covertness inherent in the submerged platform. Figure 4.17 summarizes the mission priorities established at the conference.

CAPABILITIES

The ability of the NR-2 to operate on or near the bottom was the most highly valued capability, followed by a large ocean interface. The level of redundancy required of NR-2 exceeded that of NR-1 in order to support projected operations. The least valuable capability was the ability to operate under ice (Figure 4.18). Table 4.2 provides the threshold values for these capabilities.

CONCEPTS OF OPERATION

Concepts of operation for actual execution of these mission profiles are included in Appendix C.

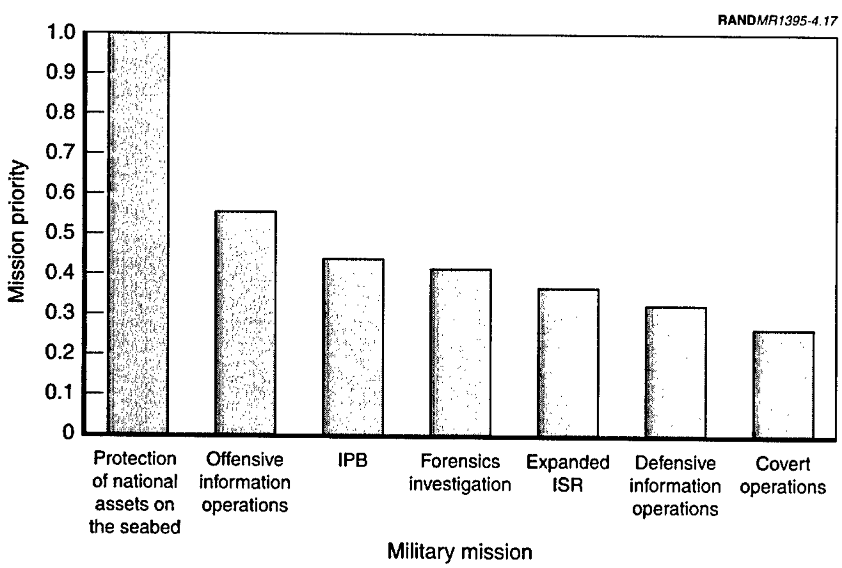

Figure 4.17—NR-2 Military Mission Priorities

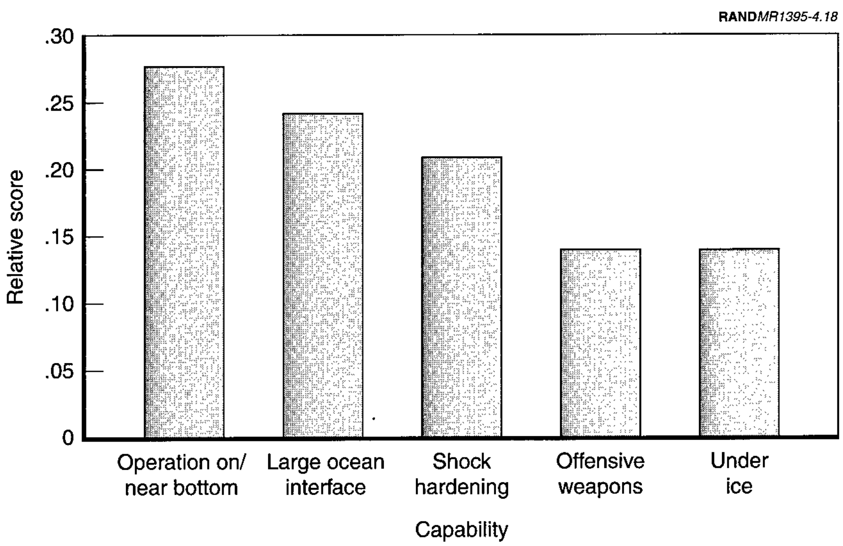

Figure 4.18—Design-Driving Capabilities Prioritization

Table 4.2

Capability Threshold Values

Capability	Value
Acoustic quieting	SSN-688 to state of the art
Large ocean interface	Essential
Transit speed	14–18 knots
Endurance	60 days
Depth	1,000 meters with adjuvant vehicle
	1,000 meters without adjuvant vehicle
Under ice	Not required
Burst speed	16–20 knots
Shock hardening	Lowest priority

Chapter Five

CONCLUSIONS

OVERVIEW

The NR-1 was built quickly in 1969 with state-of-the-art technology as an ocean engineering and ocean research support submarine. During its lifetime, capabilities increases required by mission taskings remained fairly constant. The last 10 years and this report suggest that the single outstanding design characteristic of an NR-2 must be the ability to accommodate a steadily increasing rate in the growth of capability.

NR-2, if built, is likely to be a platform of greater national importance than the NR-1, considering that the information infrastructure placed on the sea bottom in 2001 alone exceeds by orders of magnitude the entire interregional geostationary satellite transponder capacity (Appendix I). In addition, the importance of the ocean sciences and related environmental and global issues are being increasingly recognized. Furthermore, the NR-1 has not been extensively used as a military support platform. On the other hand, without the capabilities that could be provided by such a system as the NR-2, Joint Vision 2020's goal of full-spectrum dominance is forfeited with respect to the oceans.

Investment Considerations

The private sector was considered as a possible provider to support this national requirement. In the case of the NR-2, the following

statements constitute the preliminary judgment of the RAND researchers: [1]

- The private sector will not provide the range, breadth, and depth of expertise and information that the NR-2 will likely be tasked to provide because such an investment would be unprofitable.
- Information the NR-2 will provide would not or could not be reliably collected by private-sector or alternative platforms because it would be too operationally or technologically demanding.
- The private sector and other platforms would not or could not collect the information the NR-2 could be called on to collect because risk or other constraints would prevent the attempt.
- NR-2 will at times be required to provide specific tailored products independently (or combined with other sources) to U.S. agencies (Berkowitz and Goodman, 2000).

MISSIONS

In terms of missions, this study concluded that the NR-2 should be capable of executing the missions listed in Table 5.1.

Table 5.1

The NR-2's Military and Science Missions

Military	Science Support
Protection of national assets on the seabed	Physical oceanography
IPB	Ice science
Forensics/investigation	Geology and geophysics
Expanded ISR	Marine biology
Offensive information warfare	Ocean engineering
Defensive information warfare	Environmental science
Covert operations	Chemical oceanography
	Atmospheric science
	Maritime archeology

[1]RAND recommends that the issue of obtaining these required capabilities commercially be further examined in the course of the AoA study.

CONCEPTS OF OPERATIONS

The substantive difference between NR-1 and NR-2 CONOPs stems from the potential increase in the likely demand for NR-2 to contribute to national security (both military and other) requirements over her lifetime in contrast to NR-1. This difference reflects itself in two areas: speed and support CONOPs.

In terms of speed, if the NR-2 is to be responsive to both theater and NCA taskings, it must have a higher transit speed capability than the NR-1. In addition, if it is to be used increasingly as a military asset and on occasion employed in covert operations over its lifetime, a recommended "burst" speed capability has also been determined. This speed is adequate to allow clearing of datum for a reasonable period of time in case the OIC feels the situation merits this action.

Regarding the support concept, although surface ship support clearly has proven of great merit in past NR-1 science support missions, consideration should be given to designing NR-2 for capability to conduct missions autonomously if higher emphasis is to be placed on military or NCA support missions. The implications and limitations of surface ship consort on covert missions are clear. Support concepts were discussed in Chapter Four.

CAPABILITIES

Design-Driving Capabilities

Two alternative designs for NR-2 emerged from the three NR-2 conferences. Both alternatives would share design flexibility, ample payload capacity, and the ability to operate at depths to 3,000 feet and to bottom. Both would be able to operate an adjuvant vehicle (an ROV/AUV) with a manipulator and would themselves have fine manipulators. Both would have a burst speed capability of 15 to 20 knots. Neither would carry weapons or would have shock hardening, and neither would be designed for under-ice operation.

One design concept, clearly preferred in the military conferences, is for a submarine capable of autonomous operations under all conditions. It would have transit speed (15 to 20 knots) to enable timely response to NCA tasking; endurance (about 60 days) to give it useful

time on station; and, for missions in hostile waters, the stealth (state-of-the-art acoustic and magnetic quieting) to avoid undesired encounters.

An alternative design concept is for a submarine capable of autonomous operations under all but the most stressing conditions. The concept of an NR-2 working with an SSN escort was preferred to a fully autonomous NR-2 by about a third of the military CONOPs conference participants. The Alternative Design Concept NR-2 would have a transit speed of 10 to 15 knots, about 45 days of endurance, and acoustic and magnetic quieting comparable to the SSN-688. It would be acoustically quiet at low speeds (6 to 10 knots) but might be relatively noisy at higher speeds. It would be designed for SSN tow or "piggyback." The SSN escort would compensate for the NR-2 level of quieting. This submarine could perform most military missions autonomously. It could, for example, autonomously inspect bottom objects on the U.S. continental shelves. In response to urgent NCA tasking, it could be towed into an AOI, and the SSN escort could recover it after it performed its mission. The SSN would remain in the region as the NR-2 conducted its mission.

Table 5.2 summarizes two design concept alternatives' support for science and military mission objectives for the 16 missions noted.

Although the Alternative Design Concept NR-2 is clearly less capable than the Preferred Design Concept NR-2, it would probably be more affordable. Cost savings would come from the following:

- Reduced quieting requirements, especially at speeds above 10 knots.
- Reduced propulsion plant size reflecting reduced transit speed requirement.
- Reduced need for redundancy.
- Reduced endurance requirement.

The Alternative Design Concept for NR-2 would be capable of conducting science missions autonomously.

Both design concepts robustly support the majority of ocean science mission needs. The RAND team acknowledges the support for

under-ice capability expressed by civilian experts in ocean science and reflected in the body of the report. Absence of under-ice capability is based on the following key points:

- The inclusion of under-ice capability requires compromise. Other capabilities would be displaced in this small submarine to accommodate the additional ship control and safety features required for under-ice operations (as a result of the proposed CONOPs, the *redundancy* needed for operation under the ice will be included in both design concepts).[2]
- Arctic capability affects different branches of science to varying extents. Also, current and likely future methods are or will be available to obtain needed information in the Arctic—for example, ice thickness. See *Assessing the Benefits and Costs of a Science Submarine* (Meade et al., 2001), which provides a good amplifying discussion of the specific capabilities of the submarine to science in the Arctic.
- Although many important science missions for the NR-2 could be under-ice, there remains ample science to be supported in the open ocean. Both design recommendations stress the need for the NR-2 to strongly support the widest synergetic selection of science and military missions.
- Experts see no current need for under-ice capability for military missions.

In stressing missions the Alternative Design Concept NR-2, operating jointly with an SSN, would inevitably be more prone to detection than the Preferred Design Concept NR-2, but the Alternative Design Concept would have the advantage of SSN protection. Also, it is not clear that the Alternative Design Concept NR-2 would be on station long enough for an adversary to have a chance to exploit its greater detectability.

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[2]The assessment of relative impacts of specific capabilities on design is outside the scope of this study. RAND recommends that the Navy explore the trade-offs associated with under-ice capability for an NR-1 replacement.

Table 5.2

Design-Driving Values

Mission	Capability												
	Burst Speed (kt)	Transit Speed (kt)	AOI Speed (kt)	Test Depth[a] (m)	Acoustic Quieting	Mag Quieting	Operate on or Near Bottom	Reposition on or Near Bottom	Under-Ice	Offensive Weapons	Ocean Interface	Shock Hardening	Endurance (days)[b]
Science													
Physical oceanography	N/A	10	N/A	1,000	N/A	N/A	Yes	N/A	Yes	N/A	Yes	N/A	30
Ice science	N/A	10	N/A	250	N/A	N/A	No	N/A	Yes	N/A	Yes	N/A	30
Geological and geophysical	N/A	8	N/A	1,000	N/A	N/A	Yes	N/A	Yes	N/A	Yes	N/A	30
Marine biology	N/A	10	N/A	1,000	N/A	N/A	Yes	N/A	Yes	N/A	Yes	N/A	30
Ocean engineering	N/A	10	N/A	1,000	N/A	N/A	Yes	N/A	Yes	N/A	Yes	N/A	30
Environ science	N/A	10	N/A	1,000	N/A	N/A	Yes	N/A	Yes	N/A	Yes	N/A	30
Chemical oceanography	N/A	10	N/A	1,000	N/A	N/A	Yes	N/A	Yes	N/A	Yes	N/A	30
Atmospheric science	N/A	10	N/A	300	N/A	N/A	No	N/A	Yes	N/A	Yes	N/A	30
Maritime archeology	N/A	10	N/A	1,000	N/A	N/A	Yes	N/A	Yes	N/A	Yes	N/A	20

Table 5.2—continued

	Capability												
Mission	Burst Speed (kt)	Transit Speed (kt)	AOI Speed (kt)	Test Depth[a] (m)	Acoustic Quieting	Mag Quieting	Operate on or Near Bottom	Reposition on or Near Bottom	Under-Ice	Offensive Weapons	Ocean Interface	Shock Hardening	Endurance (days)[b]
Military													
Protect assets	15–20	14–18	8–10	1,000	SOTA[c]	SOTA	Yes	Yes	No	No	Yes	No	60
IPB	15–20	14–18	8–10	1,000	SOTA	SOTA	Yes	Yes	No	No	Yes	No	60
Forensics/invest	15–20	14–18	8–10	1,000	SOTA	SOTA	Yes	Yes	No	No	Yes	No	60
Expanded ISR	15–20	14–18	8–10	1,000	SOTA	SOTA	Yes	Yes	No	No	Yes	No	60
Offensive IO	15–20	14–18	8–10	1,000	SOTA	SOTA	Yes	Yes	No	No	Yes	No	60
Defensive IO	15–20	14–18	8–10	1,000	SOTA	SOTA	Yes	Yes	No	No	Yes	No	60
Covert ops	15–20	14–18	8–10	1,000	SOTA	SOTA	Yes	Yes	No	No	Yes	No	60
NR-2 concept													
Preferred	15–20	15–20	10	1,000	SOTA	SOTA	Yes	Yes	No	No	Yes	No	60
Alternative	15–20	10–15[d]	10	1,000	688–SOTA[d]	688–SOTA[e]	Yes	Yes	No	No	Yes	No	45[f]

[a]Given ROV/AUV capability.
[b]On-station days for science, total days for military.
[c]State of the art.
[d]Possibly greater with support ship tow.
[e]State of the art up to AOI speed.
[f]Military endurance requirement can be met with support ship.

Ancillary Characteristics

The following ancillary characteristics were recommended for incorporation into NR-2 as a result of the military conferences.[3] While important, they are viewed as not driving design or cost:

- Fine-object manipulation (force feedback with plug-and-play variants: ability to operate screwdriver).
- ROV/AUV capability.
- Adaptable hull fittings for sensors.
- Heavy-lift capability.
- High-data-rate (HDR) communications capability.
- Jetter/dredge capability.
- Defensive weapons.
- 3-D external viewing capability.
- Fine ship position control (on or near the bottom).
- Covert communications capability.
- State-of-the-art atmospheric control.

The following lists include the principal ancillary characteristics recommended for incorporation into the NR-2 based on the science and military missions detailed in Chapters Three and Four.

Sensors:

- Modest passive sonar
- Tactical picture
- Defensive actions/evasion
- Nonpenetrating periscope

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[3]This chapter includes the ancillary characteristics recommended by COMSUBLANT and COMSUBPAC for incorporation into the NR-2.

- High-resolution sidescan sonar
- High-definition laser and optical imaging
- Modest signals intelligence add-on equipment optimized for M/F antenna
- Accurate long-term bottom navigation
- Clip-on external sensor banks.

Ship Control:

- Improved stability in shallow water
- Automatic depth control system (hovering to plus or minus 1 foot)
- Ability to control search speed within one-quarter knot
- Ability to control angle within one-quarter degree
- Improved thrusters for operations in currents up to 3 knots
- Buoyancy control in mixed water
- Ability to rapidly change ship's angle and stabilize at communications depth
- Ability to rotate within own ship length
- Water temperature 28–98 degrees Fahrenheit
- Salinity 30–36 parts per million
- Ice pick
- Emergency propulsion for 220 nautical miles at 3 knots.

Communications:

- Covert (radio frequency and acoustic)
- Multifunction/nonpenetrating HDR antenna.

Other:

- ROV/AUV capability
- Force feedback manipulator with plug-and-play variants

- Improved acoustic and electromagnetic quieting
- Externally mounted self-defense system
- Ability to dock with mother submarine
- Transport via mother submarine or surface, tow speed 20 knots
- Bury one-eighth-inch fiber and four-inch coaxial cable
- Heavy lift (greater than 10,000-pound capacity)
- External keyway mount (10,000-pound capacity)
- Limited under-ice—no routine surfacing
- Through-hull vertical tube for object deployment
- Habitability technology improvements
- Selected redundancy improvements
- Mission-critical items at least one backup under-ice
- Onboard logistics
- Power distribution.

Appendix A

AGENCY INPUTS

During the Scientific Missions Conference for a Potential Follow-On to NR-1, several agencies submitted suggested capability requirements.

Woods Hole submitted the following list:

- Independent operations (no support ship except possibly in the Arctic in which case perhaps USNS *Healy* could fulfill that role).
- 10–15 knot speed.
- 30-day endurance.
- Large, well-equipped lab.
- Accommodations similar to a surface research vessel (R/V) for a science party.
- Acoustically, electromagnetically (E/M), and electro-optically (E/O) quiet.
- Full suite of hull-mounted and towed sensors with robust onboard data archiving and registration. These must be simple to operate, virtually hands-off, state-of-the art, and "plug and play."
- Able to operate ROVs and other tethered instruments while submerged.
- Able to launch and recover AUVs and other untethered vehicles/instruments.

- Dynamic Positioning System (DPS)—hover, track line (submerged).
- Submerged clean saltwater sampling.
- Capable of high-speed (greater than 14 knots) geological (and other) surveying, including swath bathymetry, backscatter, gravity, magnetic swath ice profiling, and sound velocity profile (SVP).
- Gender neutral (i.e., to accommodate mixed-gender crews without modification).
- Consider towed arrays capabilities.

NOAA suggested that the submersible should:

- Be configured so that scientists can use it efficiently.
- Have a built-in ROV.

The National Science Foundation said a submersible might be appropriately used in some commercial ventures serving both national and commercial needs, including the following:

- Salvage.
- Marine construction engineering.
- Deep-sea engineering.

The Interior Department's Minerals Management Service called for:

- Deep-sea oceanographic research using manned and unmanned submersibles.
- The ability to assist in offshore oil and gas production.

Appendix B

PRIOR STUDIES

This appendix presents data resulting from two notional designs done in 1999 and one done in 1990. That information is juxtaposed with statistics about the NR-1, which dates to 1968.

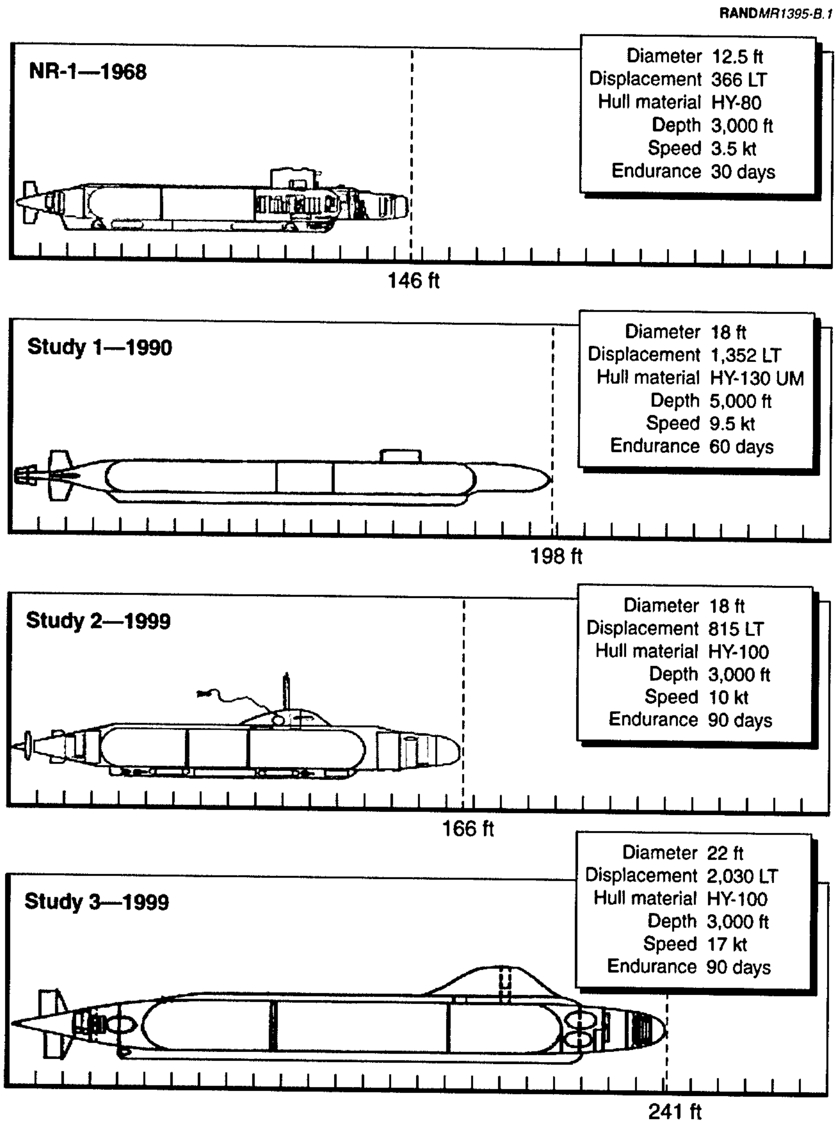

Figure B.1—NR-1 and Replacement Study History

Table B.1

NR-1 and Replacement Studies—Historical Capabilities Matrix

Capability	NR-1 1968	Study 1 1990	Study 2 1999	Study 3 1999
Speed submerged, knots (sustained; burst)	3.5; N/A	9.5; N/A	10; N/A	9.3; 17 for 5 hours
Tow speed, knots	10 surface/11 submerged	15	15	N/A
Propulsor	TS[a] Open	SS[b]	SS—external electric drive	SS
Positioning system	Thrusters fore and aft; trim system	Thrusters fore and aft; trim system	Thrusters fore and aft; trim system	Thrusters fore and aft; trim system
Appendages	Box keel	Box keel	Box keel; advanced sail; X-stern	Box keel; advanced sail; X-stern
Arctic operations	No	Yes	No	No
Seawater density[c]	64.3/63.8	64.3/63.4	N/A	64.3/63.6
Special variable ballast requirements	Bottom sitting and heavy lift	Bottom sitting and heavy lift	N/A	N/A
Quieting (acoustic and nonacoustic)	None	SSN-21 technology—nonacoustic no more detectable than acoustic	Acoustically isolated decks; electromagnetic and wake minimization	SSN-21 noise goals at 10 knots

Table B.1—continued

Capability	NR-1 1968	Study 1 1990	Study 2 1999	Study 3 1999
Adjuvant vehicle operations (UUV/UAV/ROV)	None	Transport, launch, and retrieve vehicles; UUV housed in box keel 45 inches by 40 feet; 2,000-yard tether capacity; dry access	ROV/AUV hangar bay	UUV housed in sail
Endurance				
Accommodations	7	15	9	9
Maximum complement	11 plus 2 riders	15	11 plus 2 riders	13
Provisions	30 days	60 days	90 days	90 days
Weapons	None	None	None	None
Navigation	DR; OAS; periscope; TV camera; deployable CTFM[d] transponders	Integrated system like *Dolphin*; ROV navigation and tracking	Advanced navigation system	N/A
Communications	Underwater telephone; MF/HF/UHF radio; intercom system; video/voice recorder	*Dolphin*-type basic suite	Underwater and HDR/RF communications	Better fleet connectivity; RF data link; RF/acoustic data link
Sensors	Side-scan; OAS; bottom mapping	Active—DS/OAS,[e] and bottom mapping; passive—BQR-21	OAS	N/A
Special warfare	None	None	Mission module—sail and box keel	Reconfigurable space—OPS/box keel/forward NPH[f]

Table B.1—continued

Capability	NR-1 1968	Study 1 1990	Study 2 1999	Study 3 1999
Payload modularity ocean interface	Manipulators	Manipulator; lights and cameras; mission module for heavy-lift or ROV	Faired manipulator; lights and cameras housed for transit survivability	N/A
Object recovery	Tines—10,000-pounds heavy lift	Tines—10,000-pounds heavy lift	N/A	N/A

[a]TS = twin screw.
[b]SS = single screw.
[c]Measured in pounds per cubic foot.
[d]CTFM = continuous transmission frequency modulated.
[e]DS/OAS = deep submergence obstacle avoidance sonar.
[f]NPH = nonpressure hull.

Appendix C

CONOPs FOR NR-2 MILITARY AND SCIENCE SUPPORT MISSIONS

PURPOSE

This appendix is intended to summarize concisely the means by which previously presented NR-2 operational requirements were developed in the context of likely NR-2 missions.

Representative groups of potential NR-2 missions were examined and developed in detail by national security experts and experienced operators[1] to establish NR-2 operational requirements. Logical mission groups were established: *those dealing with man-made objects placed on the bottom of the sea, forensic operations gathering or examining evidence (such as debris), support to covert military operations, or support to science or military research and development.*

Despite their distinct objectives, the mission groups share the common phases of predeployment, transit to an operating area, activities in the operating area, return from the operating area, and post-mission wrap-up. All mission phases, with the exception of post-mission wrap-up, were found to influence NR-2 operational requirements. The other four mission phases were used to frame NR-2 operational requirements initially.

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[1]These included representatives of both fleets, the Navy staff, NAVSEA, and the Office of Naval Intelligence.

ASSUMPTIONS

A minimal NR-2 capability was used as a baseline over which additional requirements were applied. Missions were determined to require up to 45 days of operation on station.[2] Military missions were projected to be conducted from Groton, Connecticut, or Pearl Harbor, Hawaii.[3] Total endurance of about 60 days, including transit time, was derived. Initial mission planning was assumed to reflect NR-2 capabilities—it would not be given a mission beyond its capabilities (including endurance) or which it could not conduct safely.

NR-2 transits to and from operating areas, exclusive of tug support or mooring upon return, could be conducted with or without outside support. Similarly, on-station activities could be conducted with or without outside assistance. All combinations of outside support were examined.

Any offensive weapons or mines were not assumed to be stored inside the NR-2 pressure hull.

MISSION PROFILES BY PHASE

Predeployment

A six-month predeployment period is anticipated as typical for planned NR-2 missions. Any equipment to be installed, as well as equipment responsibility, will be identified at the outset. Equipment decisions might reflect regional threat assessments along with mission objectives. Insertion of new equipment could be expected to impact tightly integrated existing equipment or overall NR-2 operation. Maximum NR-2 depth or speed, for example, could be limited. Such impacts will be evaluated prior to equipment installation. Also, any temporary modifications to NR-2 required for new equipment will also be evaluated prior to equipment installation.

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[2]This requirement was derived from a review of prior NR-1 classified and unclassified missions combined with a projection of future mission profile requirements to include transit times.

[3]To help put these home port assumptions as well as military missions in context, refer to Khalilzad and Lesser (1998) and Khalilzad et al. (2001).

Newly installed equipment will normally be tested at sea and the crew trained in its operation before the ship deploys on a mission, and projected operational limitations will be verified. If the NR-2 is to be towed by or mated to another ship for a transit, ability to operate in those modes will be demonstrated at planned speeds.

Specialists might also be required for some missions. They will be selected before the predeployment phase and integrated into the ship's crew during this phase. Becasue space on NR-2 will be at a premium, mission specialists may replace crewmembers for selected tasks.

Any unique mission objectives and any operational constraints imposed by new equipment will be codified in orders to the crew. They will be tested using installed equipment shortly prior to departure, using a "Fast Cruise" conducted in port, with at-sea conditions simulated and all required equipment placed in service for test.

Transit to the Operating Area

Safe operation and adherence to local regulations will always be required as NR-2 leaves port. A level[4] of seaworthiness on the surface, running lights, and navigational radar will be required.[5] NR-2 missions could be delayed by inability to operate safely on the surface. If the NR-2 is to transit to the operating area with a support ship, they will rendezvous before beginning their transit. This would require modest navigational capability on the part of NR-2, but after the rendezvous the support ship could assist the NR-2 in navigation. A support ship could also reduce NR-2's ship-to-shore communication burden during the transit. Under some threat conditions, NR-2 and any escort may have to operate quietly as they approach an operating area.

[4]For purposes of analysis and design, the required level of seaworthiness is considered to be ability to operate on the surface in Sea State 6, using the Beaufort number system. Sea State 6 here corresponds to strong breezes of about 25 knots, with rough seas having wave heights of 8 to 13 feet (Maloney, 1985).

[5]NR-1 operates under a waiver of rules governing the location and height of running lights. Failure to meet safety requirements could result in a requirement that NR-2 exit and enter ports accompanied by an escort that meets Rules of the Road requirements.

The crew will normally rehearse the mission and practice operating within any new guidelines required by new equipment during the transit. In this period the crew might also work out planning details and contingency plans. Simulation equipment and general-purpose computers may be required for these activities.

The Marginal Ice Zone of broken ice surrounding the Arctic icecap could present a threat to the NR-2 in transit. On entering the Marginal Ice Zone, or crossing the Arctic "ice edge," NR-2 will operate deep enough to avoid the ice and will monitor surface ice with a multipurpose sonar suite. Under-ice operations at high latitudes present navigational challenges. The NR-2 will take a last fix before going under the ice, and will subsequently be required to depend on inertial navigation for long periods. Extra sensors for under-ice navigation and communication may be required. Surface ice could also threaten onboard systems and sensors, so NR-2 must be prepared to deal with surface ice.

If the operating area poses a (military or environmental) threat to any support ship or if the mission plan calls for NR-2 to operate alone, the two ships will separate, and NR-2 would subsequently operate autonomously.

Transits will provide opportunities for any specialists added to the crew to assure proficiency and equipment readiness.

NR-2 will transition to an operating mode suited for the operating area as it approaches that area. It might, for example, decrease speed and increase depth.

For missions in support of covert operations, covert communications to update tactical intelligence and any mission updates will be required just prior to entering the operating area. NR-2 may simultaneously launch a tethered communication buoy for emergency communications with its support team.

Operations on Station

As always, safety will be paramount throughout NR-2 missions, so unsafe activities will not be planned. NR-2 must be able to conduct planned activities safely. NR-2 is assumed to operate autonomously while on station. It may have to avoid detection and so must be able

to operate quietly at operationally suitable speeds and may have to follow prescribed tracks. It may have to monitor activities in the operating area to avoid possible threats. Any remotely operated vehicle to be used in this phase will be tested as the NR-2 arrives in its operating area.

The four mission groups (dealing with man-made objects on the bottom of the sea, gathering or examining evidence, support to covert military operations, or support to science or military research and development) generate distinct requirements in this phase.

Missions Dealing with Man-Made Objects on the Bottom. In missions dealing with man-made objects on the bottom, the NR-2 could be required to conduct a site survey to determine a suitable placement site. The site must be suitable for NR-2 operation while placing the object and must be suitable for object operation. Site surveys require the ability to cover significant distances over the bottom while examining it. NR-2 must be capable of deploying objects in suitable locations. Careful placement of objects on the bottom and their manipulation once on the bottom will be required. These missions can also require relocating objects previously placed on the bottom and recovering them. A requirement exists for precise navigation as the NR-2 descends and operates over the bottom.

Manipulation can include maintenance, operation, and repair—all requiring manipulator dexterity. The NR-2 may be required to maintain a fixed position (by hovering or opposing currents) to manipulate objects. Ability to hold a position on the bottom might be required. Conversely, NR-2 may be required to maneuver precisely on or near the bottom to manipulate objects from suitable vantage points. If an adjuvant vehicle (such as an ROV/AUV) is used to manipulate the object, ample lighting may be required to illuminate objects to be manipulated. Site restoration may be required to conceal activities in the area.

Support to Covert Military Operations. Of the four groups of missions, only these missions would have on-station operations conducted exclusively in hostile waters (defined as waters in which a nearby country with interests inimical to the United States has demonstrated or given evidence of an ability to control the seas). While on station, the NR-2 might interfere with identified targets

(possibly including keeping them from getting under way without the use of violence). It might also tag identified vessels in port to allow easier tracking at sea. Offensive weapons, such as mines, might also be used in support of Special Operations Forces activities. External weapon capacity would be required in that case. NR-2 will be expected to support covert IPB or covert ISR operations. NR-2 will communicate covertly while operating on station.

NR-2 will seek to minimize its time in hostile waters in the conduct of its mission. Both acoustic and nonacoustic stealth will be stressed. NR-2 will be expected to avoid detection, especially by threat submarines and tripwire systems, and to be able to break threat contacts and escape. Evasion and escape plans will be developed and well-rehearsed in predeployment training, along with plans for dealing with a target it has inadvertently alerted or that has become aware of its mission through some other means. Loss of an adjuvant vehicle is readily acceptable in noncovert operations but a response to this eventuality must be carefully preplanned and exercised prior to the mission. Thorough site restoration may be required before leaving the operating area.

Forensics Missions. NR-2 could collect water samples at varying depths, sample the bottom, or locate and retrieve evidence or analyze it on site in forensics missions. An initial search will be conducted to identify potentially interesting objects, AOIs, or bottom hazards. It would operate at speeds suited to its search sensors consistent with any security requirements and time available for search. NR-2 must maintain a safe distance above the bottom in search but stay close enough to the bottom to search effectively. When using an adjuvant vehicle NR-2 must simultaneously operate the vehicle or monitor its activities. For tethered vehicles it must also monitor the tether. NR-2 must rendezvous with an untethered vehicle when it has completed its programmed search. In either case, NR-2 must be prepared to retrieve the vehicle and may have to recharge it or replenish its power supply. Additional lighting may be required to identify objects, AOIs, or hazards. Their locations must be recorded so they can be relocated or avoided later. Navigation accuracy must also be good enough to ensure a thorough area search. NR-2 must be able to record other information and results gathered in the search. Objects of interest and AOIs would subsequently be investigated in greater detail while avoiding identified hazards. With a high

priority placed on navigation accuracy, NR-2 may have to refresh its navigation system with position updates.

NR-2 may have to lift heavy objects, store recovered objects, or uncover buried or partially buried objects in the course of these missions. Site restoration may be required for security.

Support to Science or Military R&D. These missions can be as simple as taking instruments and test objects to depths of interest. They could entail observing system performance under conditions of interest or using NR-2 as a surrogate for another platform. An accurate navigation system may be needed to achieve planned test geometries or to reconstruct exercise geometries. It may be necessary to uncover or bury objects in support of science.

The special demands of support to covert military operations are clearly orthogonal to the demands of the other missions in the sense that the NR-2 would not benefit from the capabilities required for other missions (such as the ability to operate deep on or near the bottom) in performing other missions. Similarly, the other missions would not benefit from the special demands of support to covert military operations (such as nonacoustic stealth). This suggested that missions supporting covert military operations should not be considered core NR-2 missions.

Return Transit

Extra sensors or navigational equipment may be recovered before starting return transit. If a support ship entered the operating area with the NR-2, the two will rendezvous and return to port together.

Mission data preparation may be necessary during the return transit. It may also be necessary to remove special installations and restore the NR-2 to a normal configuration during the return transit. If so, testing restored systems will also be necessary. Finally, it may be necessary to shut down equipment installed for the mission.

SUMMARY

The means by which previously presented NR-2 operational requirements were developed were presented in a condensed form

in this appendix. Absence of a possible requirement in the context of a group of missions does not mean that there is no such requirement. For example, although not mentioned, precise navigation would be required for support to covert operations. Its need is overshadowed by other requirements, and so it was omitted. The actual process of deriving requirements worked at the checklist level of detail.

All mission phases, with the exception of postmission wrap-up, were found to influence NR-2 operational requirements. NR-2 requirements were derived iteratively—starting from the assumptions that NR-2 would have 60 days of endurance and that it would not be given a mission it could not conduct safely.

Missions involving man-made objects placed on the bottom of the sea, forensic operations gathering or examining evidence, and support to science or military research and development were found to have overlapping and mutually compatible requirements. Their requirements were largely irrelevant to the other group of missions as defined in this study—those supporting covert military operations. Conversely, requirements for missions supporting covert military operations were largely irrelevant to the other mission groups. This again suggested that missions not on the ocean bottom should not be considered core NR-2 missions.

Appendix D

SUBMARINE DESIGN-DRIVING CAPABILITIES DEFINITIONS

This appendix provides short definitions of submarine capabilities that, in the view of submarine designers, are major design (and cost) drivers.

- **Burst speed:** Maximum NR-2 sustainable speed for approximately five hours.
- **Transit speed:** Maximum NR-2 speed sustainable indefinitely (days) in steady-state point-to-point operations.
- **Ingress/on-station/egress speed:** Ingress speed is the speed used on entering an AOI to maximize time on station while limiting the probability of counterdetection. On-station speed is the desired search speed in the AOI. Egress speed is the speed used to exit the AOI to minimize time there while limiting the probability of counterdetection. In general, these speeds are similar and have been grouped. They are generally exceeded by transit speed, so transit speed captures more design requirements.
- **Test depth:** The maximum unrestricted depth to which NR-2 may routinely operate.
- **Acoustic quieting:** Broadband and narrowband acoustic noise levels as a function of speed.
- **Magnetic quieting:** Electromagnetic noise reduction, usually achieved through deperming/degaussing or installed systems.
- **Ability to operate on or near the bottom:** The ability to place the ship safely on the seabed without operating restrictions on ships

systems or to operate effectively in proximity to the bottom without restrictions on ships systems while maintaining positive control of the ship under all anticipated sea conditions.

- **Ability to reposition on or near the bottom:** The ability to reposition reliably and accurately (including rotating within ship's length) while operating on or near the bottom.
- **Under-ice capability:** Ability to operate safely under the ice includes the ability to penetrate thin ice and emergency (backup) propulsion capability as well as the ability to ice pick.
- **Ocean interface:** Any large area exposed to the ocean either across the pressure hull boundary or accessible/manipulable outside the pressure hull—generally used to refer to the ability to retrieve objects from outside to inside the pressure hull.
- **Offensive weapons:** Permanently installed capability to employ undersea weapons, such as torpedoes.
- **Shock hardening:** Ability to maintain operational capability after sustaining a defined shock value to the ship.
- **Endurance:** Maximum period of operation without external support.
- **Payload:** The support equipment carried on the platform, which defines the range of mission capability.
- **Flexibility/adaptability:** Ability to accommodate additional missions without redesign or modification to the basic platform (includes plug-and-play manipulators, ROVs, external payloads).
- **Redundancy:** The incorporation of design considerations required to eliminate single-point failure modes.

Appendix E

MILITARY MISSION PROFILES

As is the case for scientific missions, profiling allows a better understanding of the transition from mission through objective to capability because "capabilities required to accomplish mission" is the essential input both to the designers of the replacement system and the AoA process that follows.

Since the replacement for the NR-1 would likely be in service over a time period of about 40 years, the objectives noted below are both retrospective and prospective. They include the results of reviews of prior NR-1 missions, and necessarily include projections of future likely objectives by participating experts.

INITIAL MILITARY MISSION PROFILES

Recovering Objects

Mission description: On these missions NR-2 would be used as a military asset to recover items or assets of value or interest on or near the ocean bottom. Refer to the NR-1 historical missions listed in Chapter Two for several examples. These could be covert or overt missions.

Mission objectives could include the following:

- Covert/overt recovery of sensitive military or other items of national interest.
- Covert tagging of wreckage for tracking upon recovery by other nations.

- Recovery of sensors previously implanted for national or military purposes.
- Recovery of components for later forensic analysis.

Systems Manipulation/Implantation/Control

Mission description: On these missions NR-2 could be used as a military asset to operate on the sea bottom to service fixed or temporary arrays, to implant sensors as necessary for added Combined Joint Task Force surveillance capability, and to assist in servicing assets on the seabed in the case of their failure. NR-2 could be used as a primary platform to assist in testing and support of advanced surveillance systems. These would generally be covert missions.

Mission objectives could include the following:

- Covertly implanting sensors for detection of evidence of chemical and biological warfare production activity.
- Covertly implanting sensors for detection of arms control treaty violation activity.
- Manipulating and disrupting various systems for specific purposes.
- Site survey/object deployment, subsequent object relocation, repair, and maintenance.

Disabling/Removing Objects

Mission description: In this mission NR-2 can be used to enable Special Operations Forces/Advanced Swimmer Delivery System (SOF/ASDS) operations by surveying/disabling and removing route interference from the ocean bottom. Additionally, NR-2 was envisioned as a covert military platform for use in cases when undersea covert support on the seabed is required.

Mission objectives could include the following:

- Site survey, object location, object fine manipulation, object retrieval stowage and transport.

Forensics/Investigation

Mission description: In this mission NR-2 would be employed as a military or national asset to collect samples of the water column and/or ocean bottom for analysis. Also, it would survey the ocean bottom to locate evidence of interest and if directed conduct recovery operations. These missions could be both covert and overt depending on tasking requirements.

Mission objectives could include the following:

- Gathering evidence from bottom sites or regions for in-situ or postmission analysis.
- Region location; surveys; debris or object examination, manipulation, and recovery.
- Activity monitoring and sampling.

Area Sanitization/Investigation

Mission description: In this mission NR-2 would be employed as a covert asset and military platform to help assure decisionmakers that the knowledge of threat condition in selected areas was enhanced. Additionally, NR-2 would be employed to ensure that continued or interim monitoring of AOIs not easily accessible to normal SSNs can take place.

Mission objectives could include the following:

- Covertly implanting undersea arrays in normally inaccessible areas.
- Conducting periodic area surveys (self/ROV) for intruders via passages that would impede the normal SSN.
- Appropriate placement and maintenance of tactical sensor systems.
- Covertly monitoring choke points for high-interest naval activity.
- Covertly tagging those who transit choke points to enable follow-on tracking.

ISR

Mission description: In this mission the NR-2 would be used to provide responsive intelligence to a commander concerning intelligence requirements within her unique capability set.

Mission objectives could include the following:

- Covertly providing responsive intelligence to the NCA or a military commander concerning the adversary's use of the ocean bottom.
- Support of amphibious warfare requirements.
- Assisting in defense of our ocean resources and enterprises (e.g., oil platforms, fisheries).
- Undersea survey of potential amphibious landing sites.

Military R&D Support

Mission description: In this mission NR-2 would support military R&D through on-vehicle (or offboard) test or NR-2 cooperation in testing. Missions can entail taking objects to their test depth, observing installed performance, or providing "deep target" services.

Mission objectives could include the following:

- Testing next-generation submarine class modules.
- Testing installed hardware, such as sonars.
- Serving as a conventional threat submarine surrogate in at-sea testing.
- Setting up/maintaining at sea test ranges (e.g., exercise minefields).

Gatekeeper

Mission description: This NR-2 mission was envisioned as a multifaceted mission in which NR-2 because of her capabilities, would enhance the Navy's ability to monitor choke points or militarily important sea-lanes either herself or by implanting appropriate

monitoring devices with the capability necessary to remotely monitor for traffic of interest.

Mission objectives could include the following:

- Covertly implanting and servicing of acoustic/other detection devices in normally inaccessible areas.
- Providing capability to monitor choke points/areas beyond reach of normal SSNs.
- Covertly placing/maintaining tactical sensors.
- Assisting in assurance of security of U.S. sensitive areas in a manner beyond the capability of other SSNs.

Diver/Special Operations Support

Mission description: In this mission NR-2 would be available to provide a range of support enhancing the capability of SOF and the planned ASDS system and their likely mission success.

Mission objectives could include the following:

- Conducting covert prehostilities bottom surveys of planned but unsurveyed ASDS routes for obstacles/impediments.
- Providing the option to ASDS of "piggyback" services to objective area to allow conservation of ASDS energy.
- Providing piggyback services from objective area.
- Being available to provide alternative for SEAL "wet ride" to/from objective area.

Search and Rescue

Mission description: In this mission NR-2 would provide a tailored sea-bottom-focused search capability for acoustic and nonacoustic search in support of submarine rescue and salvage. Additionally, NR-2 would provide a shuttle support capability between a disabled submarine on the bottom and a support rescue ship on the surface.

Mission objectives could include the following:

- Responding on warning to the indications of a missing or possibly sunken submarine.
- Conducting both acoustic and nonacoustic search of the ocean bottom for evidence of sunken submarines.
- Establishing communications with potential survivors of sunken submarines.
- Providing logistic support to potential survivors of submarine disasters.
- Taking initial steps to effect rescue of surviving personnel on board sunken submarines missions.

Underwater Logistics

Mission description: In this mission the NR-2 would transport objects or personnel to forward deployed systems to extend their on-station time.

Mission objectives could include the following:

- Transporting weapons or other equipment to forward deployed units.
- Providing logistic support to forward deployed units.

REFINED MILITARY MISSIONS

Selected Covert Operations

Mission description: NR-2 would be a military asset employed independently or in support of operations on the bottom in littorals, including harbors and shallow water, using both traditional and nontraditional means to neutralize adversary assets/systems (including vessels in port or at anchor). In addition to neutralization, this mission could include "tagging." This mission could also include covert or clandestine IPB or ISR of the ocean bottom—that is, requiring capabilities unique to NR-2.

Mission objectives could include the following:

- Impeding adversary vessels' propulsion.
- Covertly tagging adversary assets to enable tracking at suitable ranges.
- Support of covert missions into highly defended waters to degrade or disable enemy forces.
- Support of shallow water/littoral reconnaissance.
- Support of ASDS missions.
- Subverting threat sensors on the sea bottom in both shallow and deep water.
- Covert or clandestine IPB/expanded ISR (below).
- Covert offensive information operations.

Protection of National Assets on the Seabed

Mission description: In this mission NR-2 would be used as a national and military asset to ensure the integrity of national and allied seabed information infrastructures, thereby impeding any adversary attempt to physically degrade these systems.

Mission objectives could include the following:

- Providing covert capability to monitor integrity and security of U.S. and allied undersea information infrastructure.
- Providing covert capability to monitor the capability of adversary platforms/systems to degrade U.S./allied seabed information infrastructure systems.
- Responsive (all-condition) surveys of national (East and West Coasts) and military seabed infrastructure for any evidence of potential tampering or intent to tamper.
- Periodic seabed surveys of U.S. (CONUS and overseas) and allied undersea information infrastructure as required to ensure infrastructure security.
- Responsive (all-condition) deployment in the case of evidence of tampering with U.S. or allied seabed information infrastructures.

- Demonstrating U.S. capability and resolve to monitor and maintain undersea infrastructure security.

Forensics/Investigation

Mission description: In this mission NR-2 would be employed as a military or national asset to collect samples of the water column and/or ocean bottom for analysis. Also, it would survey the ocean bottom to locate evidence of interest and if directed conduct recovery operations. These missions could be both covert and overt depending on tasking requirements.

Mission objectives could include the following:

- Gathering evidence from bottom sites or regions for in-situ or postmission analysis.
- Region location; surveys; debris or object examination, manipulation, and recovery.
- Activity monitoring and sampling.

IPB

Mission description: In this mission NR-2 would contribute to the ongoing process by which uncertainties concerning the potential adversary, environment, and terrain for all types of operations are reduced. These missions would deal specifically with developing an understanding of threat networks deep under the sea and in the littoral and the extent to which adversaries were exploiting the seabed for military purposes.

Mission objectives could include the following:

- Covert sea-bottom mapping in support of potential future battlespace operations.
- Support to Special Warfare (SPECWAR) and amphibious operations by battlespace data gathering in a manner beyond other SSN capabilities.

- Assisting in maintenance of database of selected and prioritized maritime targets in support of CINC Operating Plans.
- Providing unique inputs based on capabilities (direct inputs or leave-behind sensors) including bottom terrain, and tidal, current, and SVP data.
- Detailed mapping of adversary's sensors on the (deep and littoral) seabed.
- Bathymetric/oceanographic surveys of ASDS ingress/egress routes.
- Bathymetric surveys in support of amphibious landings.
- Supporting other intelligence missions by ensuring battlespace is free of adversary tripwires.
- Supporting combat missions by helping assure commanders that battlespace is free of antiaccess systems.
- Monitoring installation of adversary subsurface sensors.
- Tracking physical connectivity of adversary subsurface sensor capability.
- Covertly laying acoustic surveillance systems sensors in adversary-controlled waters.

Expanded ISR

Mission description: In this mission NR-2 will be employed as a military asset to be used in prehostilities to collect (image intelligence, environmental, or selected other) information other SSNs or military assets cannot collect (however, this does not imply that NR-2 can collect the intelligence other SSNs can collect) in a covert nonprovocative manner (deep littoral). During advanced stages of hostilities, NR-2 can continue to provide any tactical reconnaissance associated with the deep seabed or deep littoral.

Mission objectives could include the following:

- Sampling effluents for evidence of weapons of mass destruction production.

- Imaging adversary undersea systems for analysis.
- Examining the seabed and littoral for indications of weapon or sensor implantation.

Offensive Information Operations

Mission description: In this mission NR-2 would be a national and military asset able to covertly affect an adversary's actions by interfering with or destroying an adversary's information assets on the deep seabed. These missions would deal with affecting the adversary's information assurance to achieve or promote specific objectives.

Mission objectives could include the following:

- Covert destruction of an adversary's commercial or military communication or information assets.
- Implantation of devices able to sever commercial communication cables on command.
- Covert destruction/interference with dedicated military communication assets.
- Overt operations (by NR-2 or a known NR-2 support ship) in the vicinity of an adversary's communication cables. This would degrade the adversary's confidence in assured communications.

Defensive Information Operations

Mission description: In this mission the NR-2 would be a national and military asset capable of denying adversaries the opportunity to freely exploit friendly information and information systems on the deep seabed for their own purposes.

Mission objectives could include the following:

- Examining commercial/military information and communications systems for signs of tampering.
- Recovering computer and communications equipment from crash/wreck sites.

The first of these seven missions (covert operations) could be directly related to greater/impending hostilities in the case that it involved application of force. The first mission could be conducted in littoral waters—frequently in shallow waters, less often working on the deep seabed. The other five missions, in contrast, could relate to peacetime and wartime intelligence and information-gathering activities. They could be conducted in littoral and nonlittoral waters, often in deep water and would most often be conducted on the seabed.

Appendix F

HYPSOMETRY DATA

NR-2 depth requirements were determined, in part, from examination of ocean depths in various regions of the world. Hypsometry data provided by the Woods Hole Oceanographic Institute, along with detailed hydrographic information from the Defense Mapping Agency, were used for these decisions. Samples of the Woods Hole data are provided for information purposes in this appendix for three representative regions: the North Atlantic, the North Pacific, and the Indian Ocean. Global hypsometry distribution is displayed below.

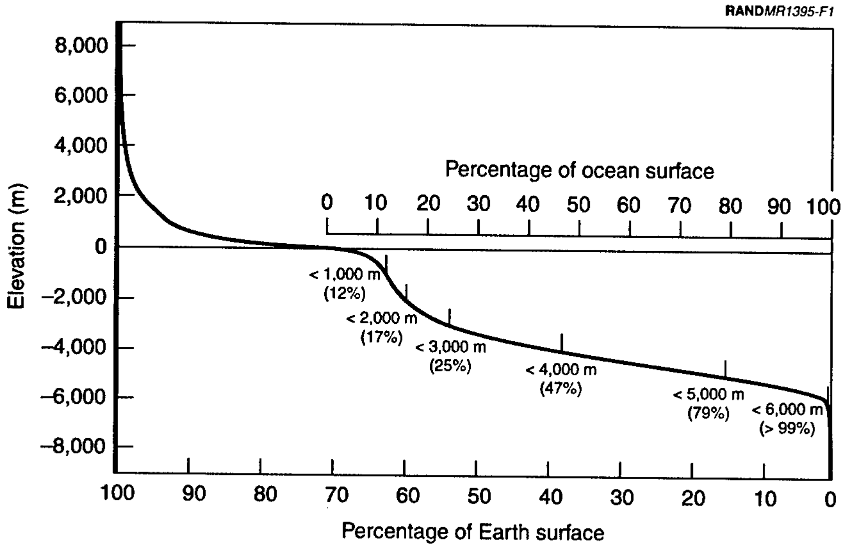

Figure F.1—Global Hypsometry Distribution

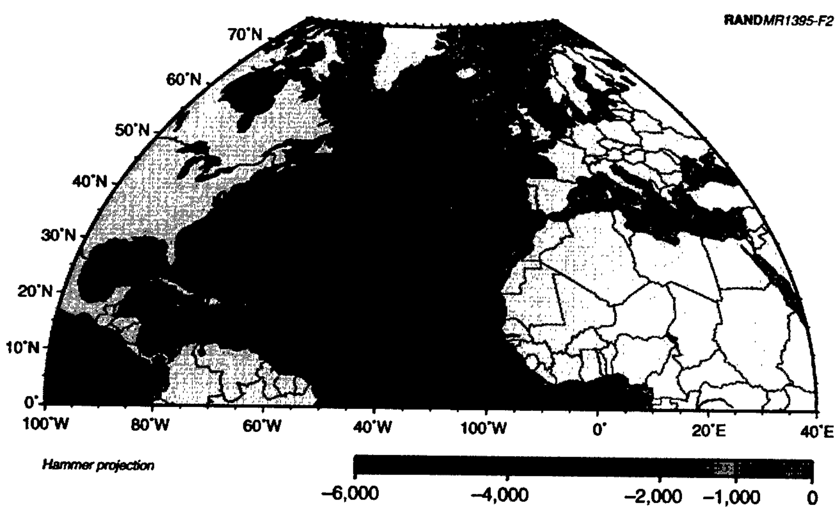

Figure F.2—North Atlantic Ocean Depth Chart

RANDMR1395-F3

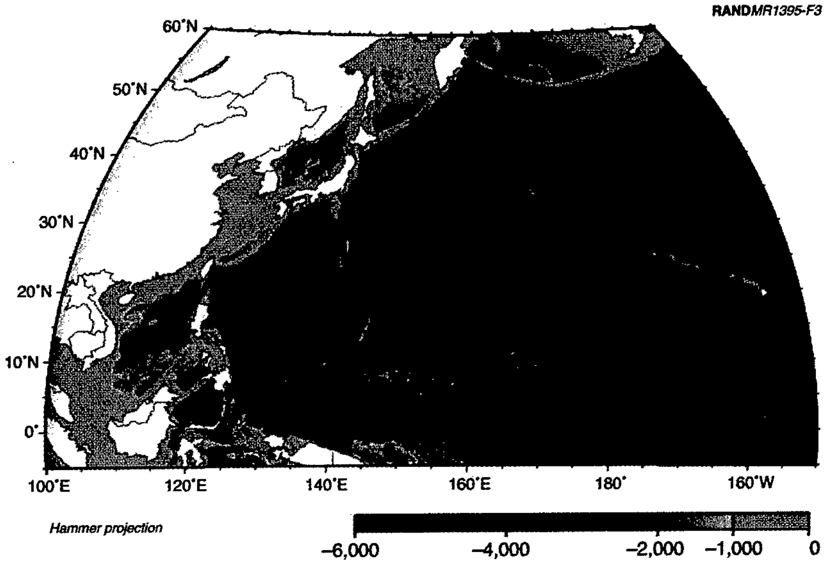

Figure F.3—North Pacific Ocean Depth Chart

RANDMR1395-F.4

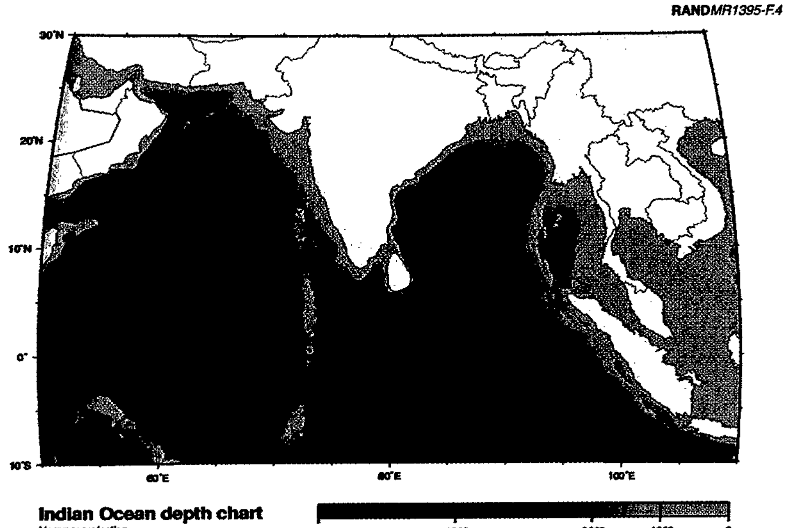

Figure F.4—Indian Ocean Depth Chart

Appendix G

NR-2 SUPPORT CONCEPTS OF OPERATIONS

Three NR-2 Autonomy Concepts of Operation (CONOPs) were used at the Military Mission Symposia. They used differing means of bringing NR-2 into AOI/AOR. They were as follows:

- *Fully autonomous operation.* NR-2 is unescorted in this CONOP, conducting an operation completely under its own power (Figure G.1).

RANDMR1395-G1

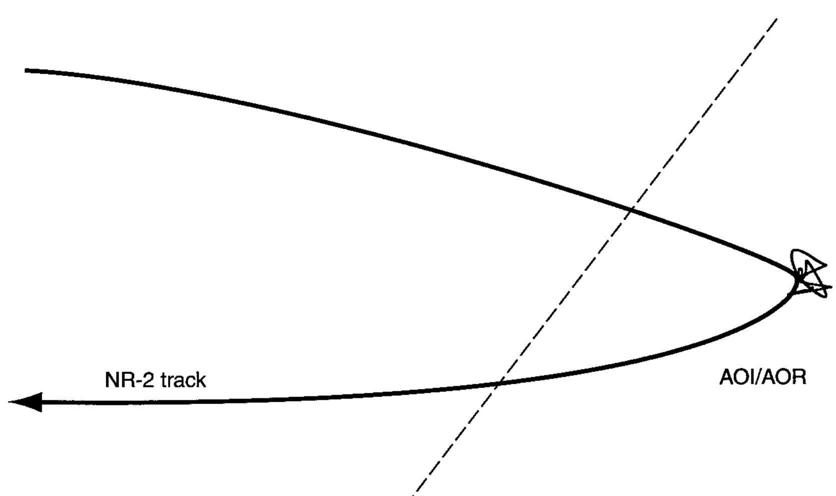

Figure G.1—Fully Autonomous CONOP

- *Operation in consort with an SSN.*[1] NR-2 is towed or carried into the AOI/AOR by an SSN, conducting only the operations in the AOI/AOR under its own power. The SSN escort operates in the AOI/AOR while NR-2 operates under its own power (Figure G.2) or the escort has the option of operating at a standoff distance from the AOI.
- *Operation in consort with a surface support vessel.* NR-2 is towed or carried to the edge of the AOI/AOR by a surface ship. NR-2 enters the AOI/AOR and returns to the surface ship escort under its own power. The surface ship escort operates outside the AOI/AOR while NR-2 operates under its own power (Figure G.3).

RANDMR1395-G2

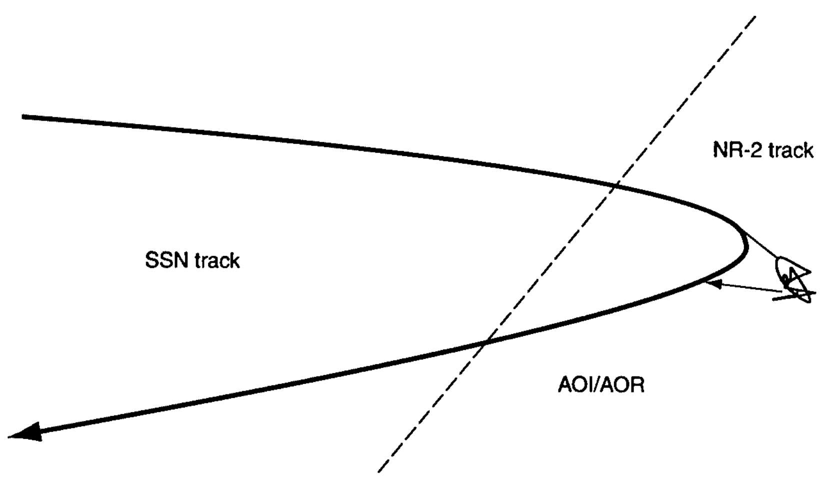

Figure G.2—SSN Support CONOP

[1]Although NR-2 would occasionally require an SSN in support, overall its capability would increase SSN force capability.

RANDMR1395-G3

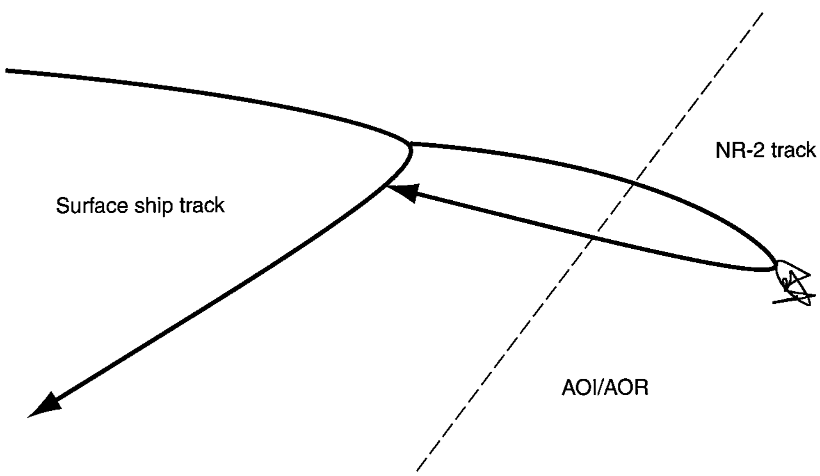

Figure G.3—Surface Ship Support CONOP

The Fully Autonomous CONOP was widely preferred by symposium participants and was developed in more detail than the other two CONOPs. A notional timeline was developed for a representative Fully Autonomous NR-2 mission. That timeline is presented in Table G.1 and is illustrated in Figures G.4–G.5. The points (A–L) in Table G.1 refer to positions in Figures G.4 and G.5.

Table G.1

Object Recovery Mission Chronology

Point	Day/Time	Activity
A	00/0000	Mission Origin—COMEX Transit to Local Operations Area
B	00/0300	COMEX Transit to AOI
C	12/0000	COMEX Mission Rehearsal (optional)
D	12/1200	AOI Penetration
E	12/1800	NR-2 Autonomous On-Station Mission Phase
F	13/0600	Initial Search and Registration of Areas
G	14/0000	Bottoming/Mission Ops (Includes Manipulation)
H	14/1200	Site/Equipment Restoration (As Required)
I	15/0000	COMEX Egress from AOI
J	15/1200	COMEX Return Transit to Local Operations Area
K	27/0000	Return Local Operations Area
L	27/0300	Return Mission Origin Point

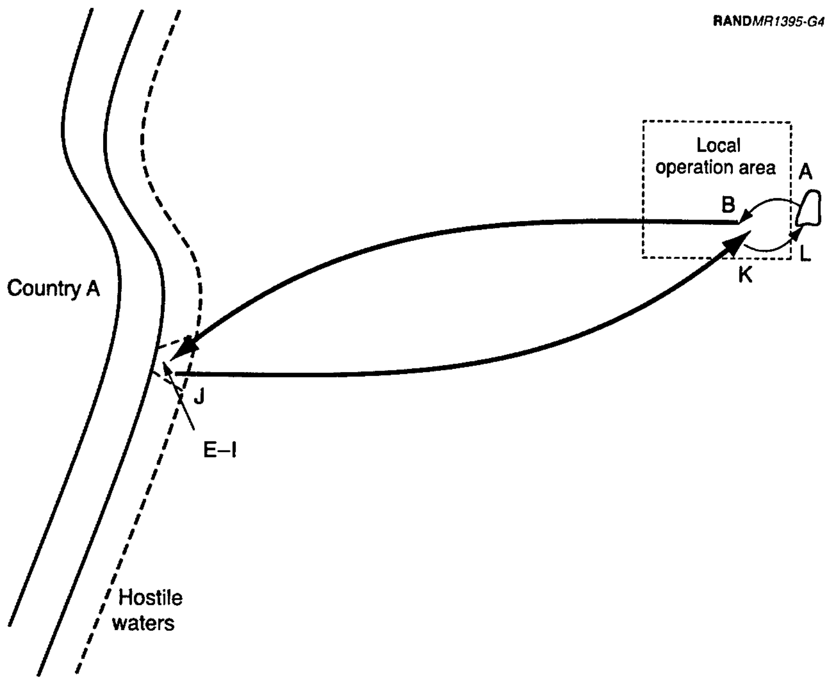

Figure G.4—Mission Overview

RANDMR1395-G5

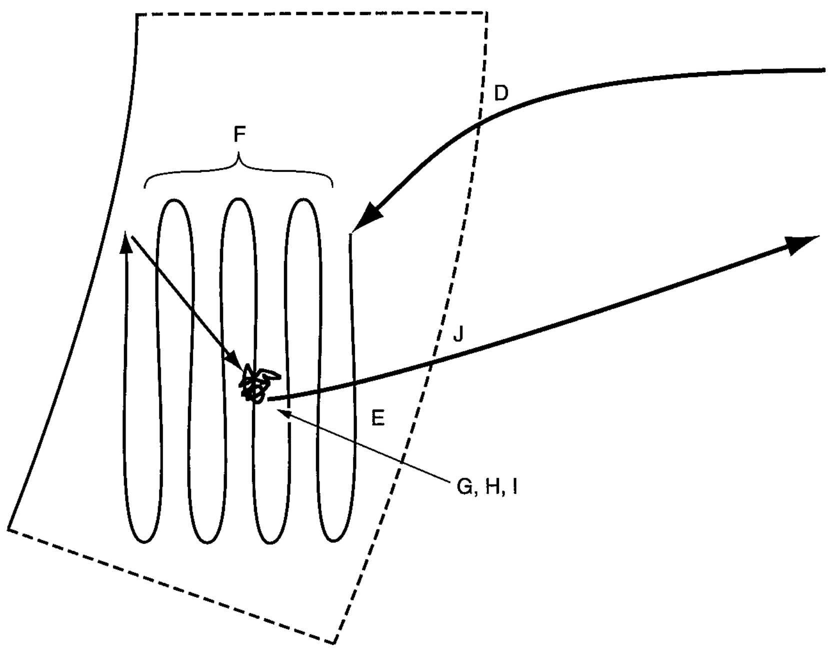

Figure G.5—AOI Operations

Appendix H

OCEANS ACT OF 2000

106th Congress
2d Session
S. 2327

AN ACT

To establish a Commission on Ocean Policy, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

Section 1. Short Title.

This Act may be cited as the "Oceans Act of 2000."

Sec. 2. Purpose and Objectives.

The purpose of this Act is to establish a commission to make recommendations for coordinated and comprehensive national ocean policy that will promote—

(1) the protection of life and property against natural and manmade hazards;

(2) responsible stewardship, including use, of fishery resources and other ocean and coastal resources;

(3) the protection of the marine environment and prevention of marine pollution;

(4) the enhancement of marine-related commerce and transportation, the resolution of conflicts among users of the marine environment, and the engagement of the private sector in innovative approaches for sustainable use of living marine resources and responsible use of nonliving marine resources;

(5) the expansion of human knowledge of the marine environment including the role of the oceans in climate and global environmental change and the advancement of education and training in fields related to ocean and coastal activities;

(6) the continued investment in and development and improvement of the capabilities, performance, use, and efficiency of technologies for use in ocean and coastal activities, including investments and technologies designed to promote national energy and food security;

(7) close cooperation among all government agencies and departments and the private sector to ensure—

 (A) coherent and consistent regulation and management of ocean and coastal activities;

 (B) availability and appropriate allocation of Federal funding, personnel, facilities, and equipment for such activities;

 (C) cost-effective and efficient operation of Federal departments, agencies, and programs involved in ocean and coastal activities; and

 (D) enhancement of partnerships with State and local governments with respect to ocean and coastal activities, including the management of ocean and coastal resources and identification of appropriate opportunities for policy-making and decision-making at the State and local level; and

(8) the preservation of the role of the United States as a leader in ocean and coastal activities, and, when it is in the national interest, the cooperation by the United States with other nations and international organizations in ocean and coastal activities.

Sec. 3. Commission on Ocean Policy.

(a) ESTABLISHMENT—There is hereby established the Commission on Ocean Policy. The Federal Advisory Committee Act (5 U.S.C. App.), except for chapters 3, 7, and 12, does not apply to the Commission.

(b) MEMBERSHIP—

(1) APPOINTMENT—The Commission shall be composed of 16 members appointed by the President from among individuals described in paragraph (2) who are knowledgeable in ocean and coastal activities, including individuals representing State and local governments, ocean-related industries, academic and technical institutions, and public interest organizations involved with scientific, regulatory, economic, and environmental ocean and coastal activities. The membership of the Commission shall be balanced by area of expertise and balanced geographically to the extent consistent with maintaining the highest level of expertise on the Commission.

(2) NOMINATIONS—The President shall appoint the members of the Commission, within 90 days after the effective date of this Act, including individuals nominated as follows:

(A) 4 members shall be appointed from a list of 8 individuals who shall be nominated by the Majority Leader of the Senate in consultation with the Chairman of the Senate Committee on Commerce, Science, and Transportation.

(B) 4 members shall be appointed from a list of 8 individuals who shall be nominated by the Speaker of the House of Representatives in consultation with the Chairmen of the House Committees on Resources, Transportation and Infrastructure, and Science.

(C) 2 members shall be appointed from a list of 4 individuals who shall be nominated by the Minority Leader of the Senate in consultation with the Ranking Member of the Senate Committee on Commerce, Science, and Transportation.

(D) 2 members shall be appointed from a list of 4 individuals who shall be nominated by the Minority Leader of the

House in consultation with the Ranking Members of the House Committees on Resources, Transportation and Infrastructure, and Science.

(3) CHAIRMAN—The Commission shall select a Chairman from among its members. The Chairman of the Commission shall be responsible for—

(A) the assignment of duties and responsibilities among staff personnel and their continuing supervision; and

(B) the use and expenditure of funds available to the Commission.

(4) VACANCIES—Any vacancy on the Commission shall be filled in the same manner as the original incumbent was appointed.

(c) RESOURCES—In carrying out its functions under this chapter, the Commission—

(1) is authorized to secure directly from any Federal agency or department any information it deems necessary to carry out its functions under this Act, and each such agency or department is authorized to cooperate with the Commission and, to the extent permitted by law, to furnish such information (other than information described in chapter 552(b)(1)(A) of title 5, United States Code) to the Commission, upon the request of the Commission;

(2) may enter into contracts, subject to the availability of appropriations for contracting, and employ such staff experts and consultants as may be necessary to carry out the duties of the Commission, as provided by chapter 3109 of title 5, United States Code; and

(3) in consultation with the Ocean Studies Board of the National Research Council of the National Academy of Sciences, shall establish a multidisciplinary science advisory panel of experts in the sciences of living and nonliving marine resources to assist the Commission in preparing its report, including ensuring that the scientific information considered by the Commission is based on the best scientific information available.

(d) STAFFING—The Chairman of the Commission may, without regard to the civil service laws and regulations, appoint and termi-

nate an Executive Director and such other additional personnel as may be necessary for the Commission to perform its duties. The Executive Director shall be compensated at a rate not to exceed the rate payable for Level V of the Executive Schedule under chapter 5136 of title 5, United States Code. The employment and termination of an Executive Director shall be subject to confirmation by a majority of the members of the Commission.

(e) MEETINGS—

(1) ADMINISTRATION—All meetings of the Commission shall be open to the public, except that a meeting or any portion of it may be closed to the public if it concerns matters or information described in chapter 552b(c) of title 5, United States Code. Interested persons shall be permitted to appear at open meetings and present oral or written statements on the subject matter of the meeting. The Commission may administer oaths or affirmations to any person appearing before it:

  (A) All open meetings of the Commission shall be preceded by timely public notice in the *Federal Register* of the time, place, and subject of the meeting.

  (B) Minutes of each meeting shall be kept and shall contain a record of the people present, a description of the discussion that occurred, and copies of all statements filed. Subject to chapter 552 of title 5, United States Code, the minutes and records of all meetings and other documents that were made available to or prepared for the Commission shall be available for public inspection and copying at a single location in the offices of the Commission.

(2) INITIAL MEETING—The Commission shall hold its first meeting within 30 days after all 16 members have been appointed.

(3) REQUIRED PUBLIC MEETINGS—The Commission shall hold at least one public meeting in Alaska and each of the following regions of the United States:

  (A) The Northeast (including the Great Lakes).

  (B) The Southeast (including the Caribbean).

(C) The Southwest (including Hawaii and the Pacific Territories).

(D) The Northwest.

(E) The Gulf of Mexico.

(f) REPORT—

(1) IN GENERAL—Within 18 months after the establishment of the Commission, the Commission shall submit to Congress and the President a final report of its findings and recommendations regarding United States ocean policy.

(2) REQUIRED MATTER—The final report of the Commission shall include the following assessment, reviews, and recommendations:

(A) An assessment of existing and planned facilities associated with ocean and coastal activities including human resources, vessels, computers, satellites, and other appropriate platforms and technologies.

(B) A review of existing and planned ocean and coastal activities of Federal entities, recommendations for changes in such activities necessary to improve efficiency and effectiveness and to reduce duplication of Federal efforts.

(C) A review of the cumulative effect of Federal laws and regulations on United States ocean and coastal activities and resources and an examination of those laws and regulations for inconsistencies and contradictions that might adversely affect those ocean and coastal activities and resources, and recommendations for resolving such inconsistencies to the extent practicable. Such review shall also consider conflicts with State ocean and coastal management regimes.

(D) A review of the known and anticipated supply of, and demand for, ocean and coastal resources of the United States.

(E) A review of and recommendations concerning the relationship between Federal, State, and local governments and the private sector in planning and carrying out ocean and coastal activities.

(F) A review of opportunities for the development of or investment in new products, technologies, or markets related to ocean and coastal activities.

(G) A review of previous and ongoing State and Federal efforts to enhance the effectiveness and integration of ocean and coastal activities.

(H) Recommendations for any modifications to United States laws, regulations, and the administrative structure of Executive agencies, necessary to improve the understanding, management, conservation, and use of, and access to, ocean and coastal resources.

(I) A review of the effectiveness and adequacy of existing Federal interagency ocean policy coordination mechanisms, and recommendations for changing or improving the effectiveness of such mechanisms necessary to respond to or implement the recommendations of the Commission.

(3) CONSIDERATION OF FACTORS—In making its assessment and reviews and developing its recommendations, the Commission shall give equal consideration to environmental, technical feasibility, economic, and scientific factors.

(4) LIMITATIONS—The recommendations of the Commission shall not be specific to the lands and waters within a single State.

(g) PUBLIC AND COASTAL STATE REVIEW—

(1) NOTICE—Before submitting the final report to the Congress, the Commission shall—

(A) publish in the *Federal Register* a notice that a draft report is available for public review; and

(B) provide a copy of the draft report to the Governor of each coastal State, the Committees on Resources, Transportation and Infrastructure, and Science of the House of Representatives, and the Committee on Commerce, Science, and Transportation of the Senate.

(2) INCLUSION OF GOVERNORS' COMMENTS—The Commission shall include in the final report comments received from the

Governor of a coastal State regarding recommendations in the draft report.

(h) ADMINISTRATIVE PROCEDURE FOR REPORT AND REVIEW—chapter 5 and chapter 7 of title 5, United States Code, do not apply to the preparation, review, or submission of the report required by subchapter (e) or the review of that report under subchapter (f).

(i) TERMINATION—The Commission shall cease to exist 30 days after the date on which it submits its final report.

(j) AUTHORIZATION OF APPROPRIATIONS—There are authorized to be appropriated to carry out this chapter a total of $6,000,000 for the 3-fiscal-year period beginning with fiscal year 2001, such sums to remain available until expended.

Sec. 4. National Ocean Policy.

(a) NATIONAL OCEAN POLICY—Within 120 days after receiving and considering the report and recommendations of the Commission under chapter 3, the President shall submit to Congress a statement of proposals to implement or respond to the Commission's recommendations for a coordinated, comprehensive, and long-range national policy for the responsible use and stewardship of ocean and coastal resources for the benefit of the United States. Nothing in this Act authorizes the President to take any administrative or regulatory action regarding ocean or coastal policy, or to implement a reorganization plan, not otherwise authorized by law in effect at the time of such action.

(b) COOPERATION AND CONSULTATION—In the process of developing proposals for submission under subchapter (a), the President shall consult with State and local governments and non-Federal organizations and individuals involved in ocean and coastal activities.

Sec. 5. Biennial Report.

Beginning in September, 2001, the President shall transmit to the Congress biennially a report that includes a detailed listing of all existing Federal programs related to ocean and coastal activities,

including a description of each program, the current funding for the program, linkages to other Federal programs, and a projection of the funding level for the program for each of the next 5 fiscal years beginning after the report is submitted.

Sec. 6. Definitions.

In this Act:

(1) MARINE ENVIRONMENT—The term "marine environment" includes—

   (A) the oceans, including coastal and offshore waters;

   (B) the continental shelf; and

   (C) the Great Lakes.

(2) OCEAN AND COASTAL RESOURCE—The term "ocean and coastal resource" means any living or non-living natural, historic, or cultural resource found in the marine environment.

(3) COMMISSION—The term "Commission" means the Commission on Ocean Policy established by chapter 3.

Sec. 7. Effective Date.

This Act shall become effective on January 20, 2001.

Passed in the Senate June 6, 2000.

Appendix I

SUBMARINE CABLE INFRASTRUCTURE

INTRODUCTION

The backbone of the nation's—and indeed, of the world's—information infrastructure is now preponderantly composed of fiber optic cables. A critical element of that backbone is the world's ever-expanding network of submarine fiber optic cables. The importance of those cables could conceivably make them a potential target or targets for other states or terrorists. This appendix briefly documents the importance of the fiber optic cable network to the United States, potential vulnerabilities in the network, and the possible ramifications for the United States of a widespread network failure brought about by an act of sabotage.

Over the past decade, the increased demand for bandwidth driven by the Internet, as well as the continuing international trend of privatization of national telecommunications industries, has outstripped by far the resources offered by satellite transmission of voice and data (Petit, 1999). Instead, the fraction of transoceanic voice and data transmitted over undersea cables has grown in the past 12 years from 2 percent to as high as 80 percent in 2000 (Mandell, 2000). As demand has grown, so have the numbers of cables on the seabed.

While experts differ on whether the world's fiber optic network faces a capacity "glut" or "crunch,"[1] it is certain that demand for higher

[1]For pieces bullish on bandwidth, see Williamson (2000), McClelland (2000), and Rowley and Ling (2000). One article suggesting a future glut is Behr (2000).

bandwidth will continue to grow, and with it, the capacity of cables—those currently existing and those soon to be laid—to grow hand in hand. Due to be completed this year, for instance, is the Southern Cross cable network, offering a quantum leap in carrying capacity in the Southern Pacific (up to 160 gigabytes per second) in a three-tiered ring totaling some 29,000 kilometers. Similarly advanced systems are due to come on-line in the North Atlantic as well, increasing the total transatlantic carrying capacity to more than 1,000 gigabytes per second, enough capacity for the contents of 200 compact discs to be transmitted every second (McClelland, 2000).

VULNERABILITIES?

These fiber optic networks offer a number of security advantages over satellite communications. Fiber optic cables are thought to be much harder to "eavesdrop" (Mandell, 2000) on than satellites and have more dependable installation and repair practices (Mandell, 2000).

However, those fiber optic cables are in many ways significantly more vulnerable than is commonly thought. Submarine cables already face many man-made and natural dangers. Anchors dropped from ships and dredging fishing nets are two of the most common (McClelland, 2000; ICPC, 1996). The occasionally volatile nature of the seabed can expose a previously buried segment of cable (ICPC, 1996). Between 1985 and 1987, AT&T found that its first deep-sea submarine fiber optic cable (laid between the Canary Islands, Grand Canaria and Tenerife) suffered periodic outages because of frequent attacks of the *Pseudocarcharias kamoharai*, or crocodile shark, on the cables.[2] In deep ocean, the cables often lie unprotected on the ocean floor; cables in areas closer to the shore, where seabed activity might include fishing, are usually both armored and buried some two to three feet deep in the ocean floor (ICPC, 1996). The cables need only be bent to suffer significant damage (ICPC, 1996).[3]

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[2]The electric fields of which, it was thought, duplicated that of the shark's prey under attack (Martin, 2001).

[3]"Any sharp bend will cause [fibers] to crack and signals to be lost" (ICPC, 1996). Even a slight bend may cause the cables to suffer significant drop-off in the strength of the signal (Held, 1999).

Security is an important issue, because these cables are an increasingly vital element of the global economy. As one analyst has noted, "the increase in demand is being driven primarily from data traffic from Web-enabled applications . . . undersea cables are becoming an integral part of the everyday telecommunications infrastructure in a world that has no boundaries" (Carlson, 2000). In short, an intentional systemwide disruption of fiber optic cables could cause significant commercial damage.

In particular, the ability of overseas firms to get reliable, real-time data regarding U.S. markets—and vice versa—could be substantially curtailed, potentially sparking a panic. In addition, an increasing amount of U.S. military communications occurs over these commercial networks. Disruption could significantly impede these communications. In all cases, of course, action would be taken to shift transmissions from the disrupted networks to other cables and satellite transmissions. But, as discussed above, the current satellite capacity is far exceeded by bandwidth demand. As we will see below, this problem becomes even more marked when examining the case of an island, such as Taiwan.

Potential Vulnerabilities

In recent years, wiring companies have focused on redundancy as an important aspect of the cable network. While early fiber optic cables were "point-to-point" systems, modern systems are configured as loops, connecting two landing stations—at least 100 kilometers away from one another—in one country to two in another. Because it would be unlikely for an isolated nautical event—a sudden shift in the seabed on which the cables rest, for instance, or an inadvertent break caused by a fishing net or a ship's anchor—to affect both cables, the systems are thought of as secure (Williams, 2000).

However, the desire for security against inadvertent nautical events may have been counterproductive. When seeking adequate termination points for cables, companies have faced a relative paucity of suitable sites (relatively isolated from heavy fishing activity and strong ocean currents), particularly on the East Coast (see Table I.1). Because of this lack of sites, and given the considerable effort in digging a trench on the seabed for the last kilometers of the cable, then

Table I.1

Submarine Cables Terminating in the Northeast United States

Cable Name	Capacity	Termination Points (U.S.)	2d Termination Point
TAT-8	280 MB/s	Tuckerton, N.J.	
BUS-1	2.5 GB/s	Tuckerton, N.J.	
PTAT-1	420 MB/s	Manasquan, N.J.	
CANUS-1	2.5 GB/s	Manasquan, N.J.	
Gemini	2 × 15 GB/s	Manasquan, N.J.	Charlestown, R.I.
TAT-14 (planned)	16 × 10 GB/s	Manasquan, N.J.	Tuckerton, N.J.
TAT-9	560 MB/s	Manahawkin, N.J.	
TAT-11	560 MB/s	Manahawkin, N.J.	
TAT-10	560 MB/s	Green Hill, R.I.	
TAT 12/13	2 × 5 GB/s	Green Hill, R.I.	Shirley, N.Y.

tunneling from the ocean bed up into a beach manhole, to bring the cable ashore, cable companies have, again, especially on the East Coast, repeatedly placed cable termination points on the same shore (Chave, 2000).[4]

The results of this "stacking" can be seen in Table I.1. Of 10 cable systems with a total capacity of about 206 gigabytes per second (assuming that TAT 14 begins operations as planned in 2001), six terminate in only one of the same three cities, Tuckerton, Manasquan, and Manahawkin, New Jersey. One—a self-healing loop—terminates in both Tuckerton and Manasquan. A sixth terminates in both Manasquan and Charlestown, Rhode Island. Theoretically, an attack on two or three of these sites—at the point where the cables come together in the undersea trench before coming ashore—could cause enormous damage to the entire system. For instance, a successful attack on trenches in Tuckerton and Manasquan and Charlestown would eliminate all but 11 gigabytes per second of carrying capacity in that region—a 95 percent cut.

Similarly, all submarine cables but one terminating in the south of the United States terminate at one of three points in Florida: Vero Beach, Palm Beach, and Hollywood.

[4]The authors are indebted to Doctor Chave for his patient description of this process.

Of course, it is important not to overstate the potential problem. After all, the United States is not isolated—some transmissions could be rerouted through systems in Canada and South and Central America. However, given that the vast majority of transatlantic and transpacific cables terminate in the United States, the prospect of a concerted attack on these cables is troubling.

Moreover, this point yields an interesting counterexample: that of Taiwan. Unlike the United States, Taiwan would be unable to depend on a vast overland information infrastructure beyond its borders in the event of damage to its fiber optic lifelines. A recent example of the chaos potentially caused by communications outages is that of Australia. One cut cable in the SEA-WE-ME-3 network leading from Australia to Singapore caused Australia's largest Internet provider—Telstra—to lose up to 70 percent of its Internet capacity (Miller, 2000; LaCanna, 2000; Park, 2000a and 2000b).

As seen in Table I.2, a recent survey of the number of international submarine cables reaching Taiwan is particularly disconcerting. Four out of five undersea fiber optic cables reaching Taiwan do so at either Fangshan or Toucheng (the fifth, a "self-healing loop" reaches Taiwan at both, meaning that both cables would have to be damaged for Taiwan to be cut off). Two more planned cables have landing

Table I.2

Submarine Cables Reaching Taiwan

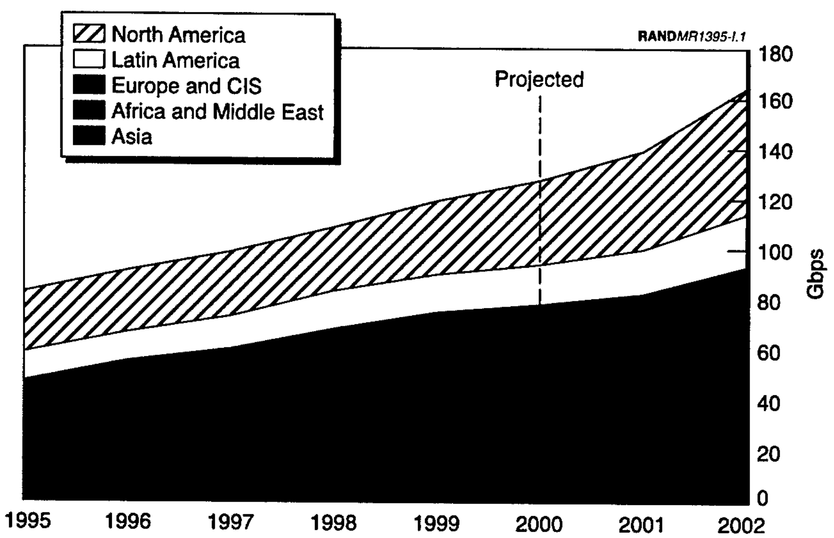
Cable	Capacity	Termination Points (Taiwan)
GPT	280 MB/s	Fangshan
Hon-Tai 2	420 MB/s	Fangshan
APC	2–3 × 560 MB/s	Toucheng
APCN	5 GB/s	Toucheng
SEA-ME-WE-3	2.5 GB/s	Toucheng and Fangshan
China-U.S. (Planned)	4 × 20 GB/s	Fangshan
APCN2 (Planned)	2fp × 8d × 10 GB/s	Tanshui
H-P-T (Planned)	4fp × 2d × 10 GB/s	Fangshan

SOURCE: Charts on the Web site of the ICPC, available at http://www.iscpc.org/cabledb.

areas at Fangshan. Only one planned cable is due not to land at either Fangshan or Toucheng. In short, Taiwan's ability to send and receive data over submarine cables might be significantly impaired by an attack on cables leading into either landing area. A well-orchestrated set of undersea attacks on the cable "trenches" at both locations might well have a sudden and calamitous effect on Taiwan's ability to communicate with the outside world. This information may well have increased relevance in light of China's renewed emphasis on information warfare.

Conclusion

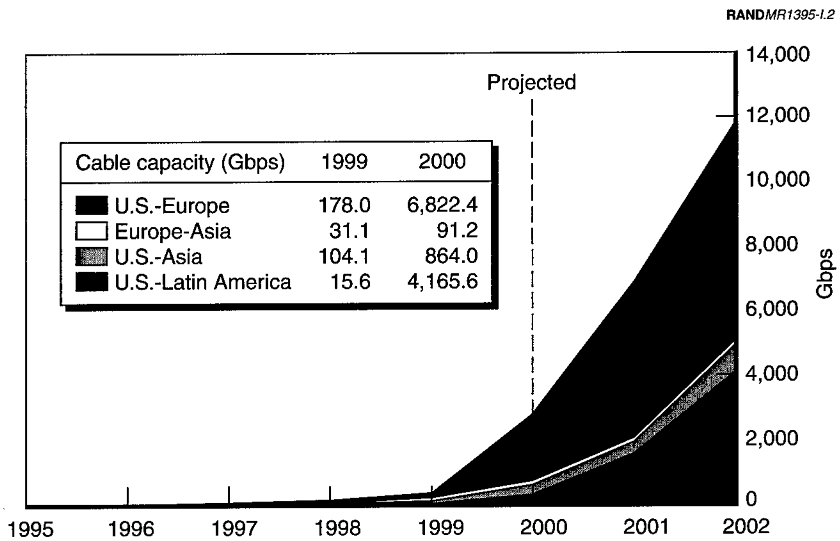
By 1969, analysts had perceived vast potential military and economic benefits in cable's exploitation (IISS, 1969). With the explosion in importance of fiber optic networks (see figures I.1, I.2, I.3, and I.4 to



SOURCE: Euroconsult.

NOTE: Chart assumes that a pair of 36-MHz equivalent transponders will yield approximately 40 Mbps transmission capacity. Transponder inventory refers to available capacity in orbit (minus satellites retired) or already under construction at the end of March 2000.

Figure I.1—Growth in Satellite Communication



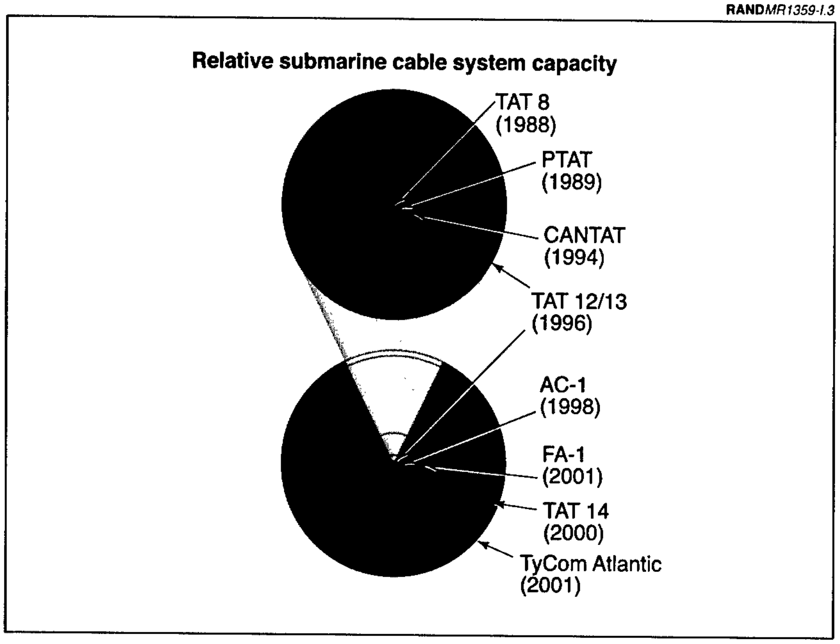
NOTE: Each 10GPS of cable capacity can carry approximately 700,000 calls at once, assuming that five call paths are derived from each standard 64 Kbps circuit.

Figure I.2—Growth in Cable Communications

compare the growths of satellite communications, cable, communications, and submarine cable bandwidth), this potential has been realized and will continue to grow; at the same time, however, so will the attendant vulnerability. The submarine fiber optic cable network is of great importance to the United States (see Figures I.5 and I.6 for a glance at the cables terminating on each coast). Moreover, constraints on cable laying mean that several cables are likely to be bundled together, offering a potentially lucrative target for sabotage.

In most industry publications, however, little attention is given to the possibility of deliberate attack on the fiber optic network. Indeed, one of the few discussions of the possibility says simply that "while undersea cables could be cut, the practice of burying the in-shore segments makes this difficult; the mid-ocean portions are hard to find without a map and help from shore-based monitoring stations" (Mandell, 2000).

RANDMR1359-I.3



NOTE: Cables are scaled to announced maximum upgradable capacity.

Figure I.3—Growth in Submarine Cable Bandwidth

Given the above, however, it is clear that more attention should be paid to the potential for deliberate attacks on the global fiber optic cable network (see figures I.7 and I.8 for a look at some of the cables terminating in Asia and Europe). Currently, for instance, shore authorities have positioned radars and occasionally scheduled flyovers for areas in New Jersey that might be targeted (Chave, 2000). The NR-2 with the capacity to maneuver and search on the seabed may be the most valuable asset of all in monitoring the status and security of cables terminating in the United States and on the shores of our allies.

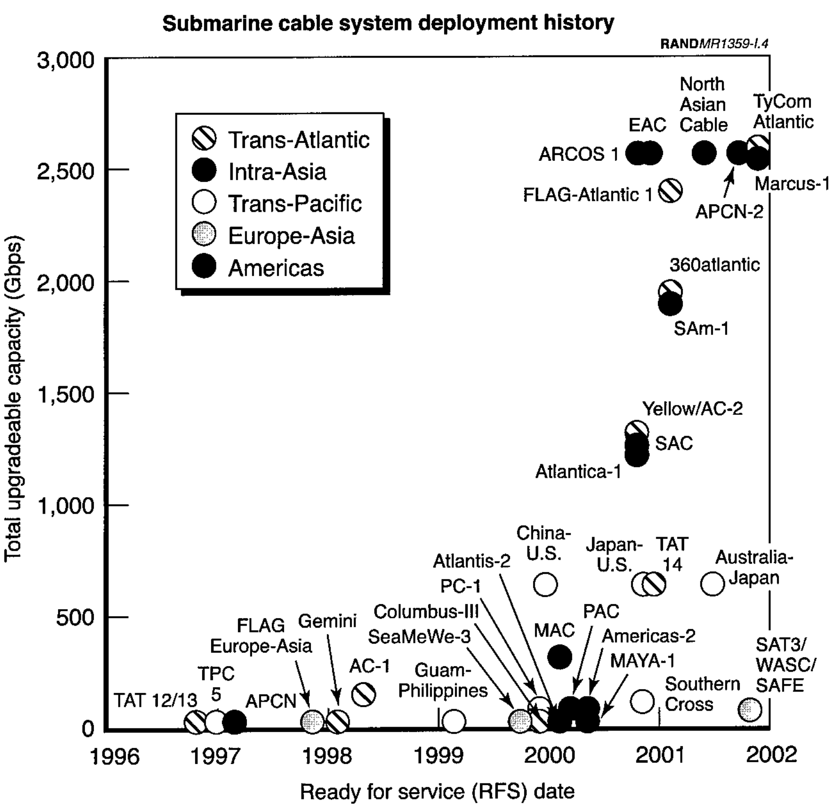


Figure I.4—Historic Growth of Submarine Cable Capacity

RANDMR1395-I.5

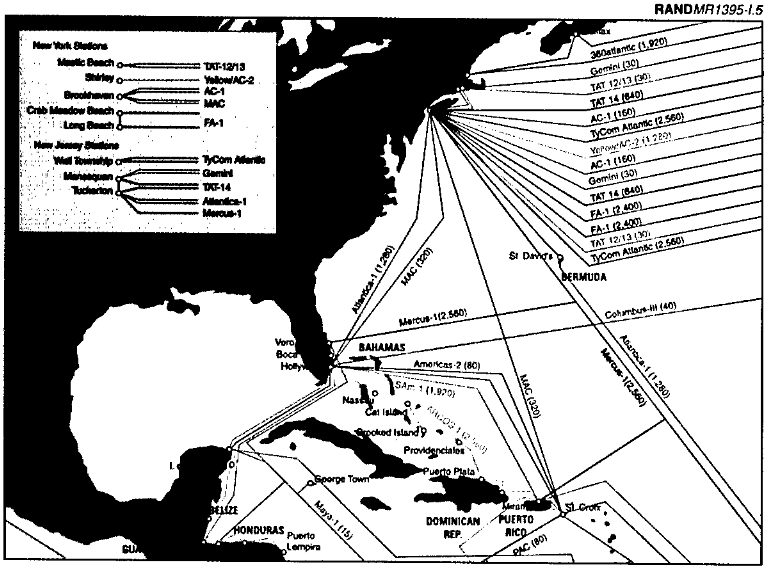


Figure I.5—Submarine Cables Terminating on the East Coast

RANDMR1395-I.6

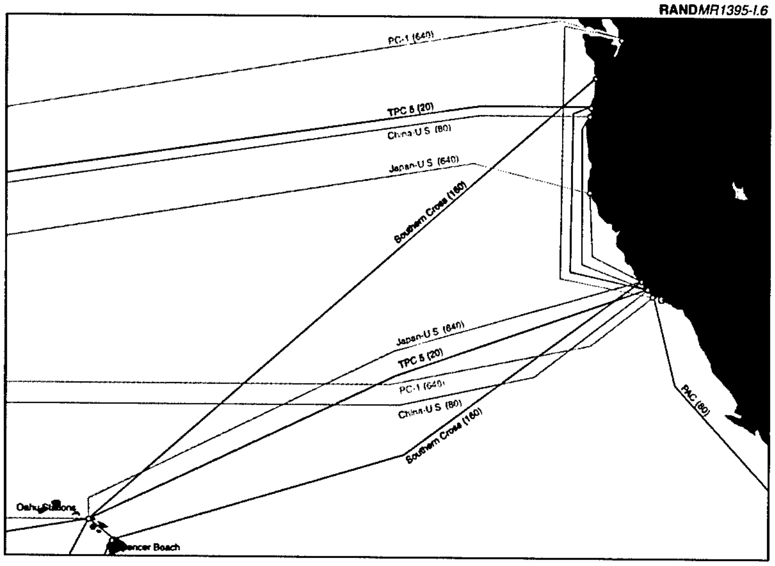


Figure I.6—Submarine Cables Terminating on the West Coast

RANDMR1395-I.7

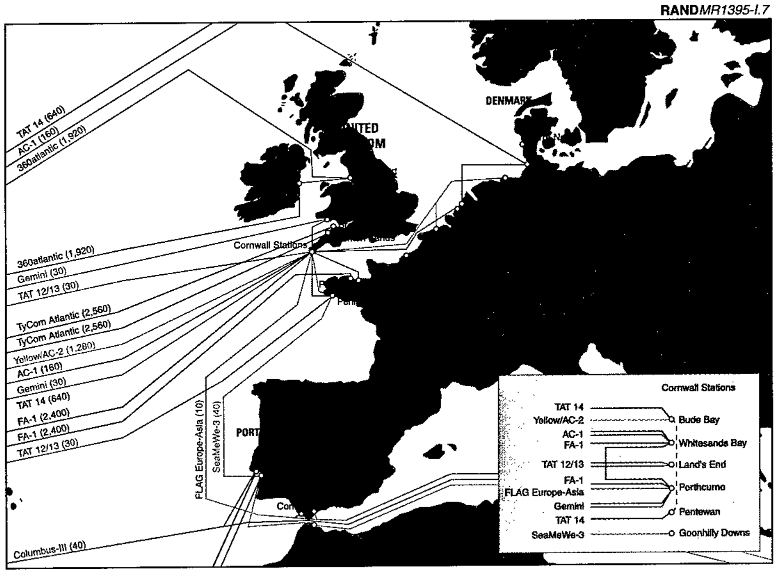


Figure I.7—Submarine Cables Terminating in Europe

RANDMR1395-I.8

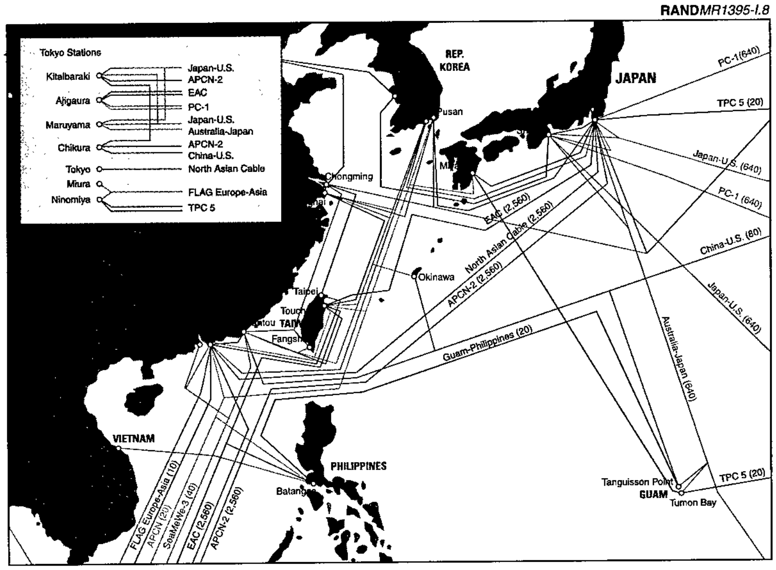


Figure I.8—Submarine Cables Terminating in East Asia

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